BIOLOGY

CONN

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AN INTRODUCTORY STUDY

FOR USE IN COLLEGES

BY

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PREFACE

THIS work is intended to serve as an introduction to the study of botany and zoölogy. It has been for some time recognized that there is a series of laws and principles which relate both to animal and plant life, and another series of important facts which refer to the relations of animals and plants to each other. In helping to a comprehension of nature, these interrelations are really of more significance than the detailed study of certain animals and plants. But with the tendency shown frequently in our educational system, to divide biology into zoölogy and botany, there is danger that these fundamental truths and interrelations be neglected, since a consideration of them belongs strictly neither to zoölogy nor to botany.

To students of the age of those in secondary schools, the study of such concrete facts as the description of animals and plants is most attractive; and for them, courses in elementary botany and zoölogy are eminently appropriate. But to students of the greater maturity of college grade, the study of the fundamental biological laws is more stimulating and better calculated to develop the thinking powers. It is, therefore, the author's belief that the proper way for older students to begin the study of the great department of biology is to consider the fundamental principles relating to both animals and plants, before either of these groups is studied in detail. After the student turns his attention more particularly to zoölogy or botany, he is likely to be engrossed in the *details* of the life and structure of animals and plants, and so almost inevitably neglects the broader fundamental laws which should correlate the phenomena of life as one science. Unless, therefore, the foundation principles of biology be studied as an introductory course, it is very probable that they will be neglected. For this reason, this text has been provided as

an introductory survey of the laws which apply to both animals and plants, and those principles which coördinate and correlate them. It is hoped that it may have some influence in developing the study of the fundamental principles of biology as an introductory course, thus supplanting the old custom of plunging the student at the outset more specifically into zoölogy or botany.

It is designed that this work shall be an elementary study of biology, on a par with, and parallel to, elementary physics and chemistry. Logically it should follow, rather than precede, these two sciences, although it may be taken simultaneously with them. Its place in a curriculum should, therefore, be about the same as that of elementary physics and chemistry; and as developed in the following pages, it belongs to the beginning of college work.

In preparing these pages, it has been recognized fully that a certain amount of laboratory work is necessary in order that the student may properly understand biological phenomena. It is also appreciated that, with the present development of the teaching of biology and the present equipment of many of our institutions, it is frequently impossible to introduce any extended laboratory work, on account both of insufficient equipment and lack of time in the already crowded courses of study. For this reason, the chapters have been arranged so that, where necessary, they can be used without the accompanying laboratory demonstrations. Although this is an undesirable method of studying biology, the author believes that the biological principles covered in the following pages may be comprehended in a fairly satisfactory manner, even though the student does not have the opportunity of making the laboratory tests. It is hardly necessary to state, however, that as much practical laboratory work as possible should accompany the study of the text. For this reason, outlines of the correlative laboratory work have been added at the end of the chapters. In all cases where laboratory work is possible, students should be required

to make careful drawings of the objects studied. Wherever time permits, the laboratory work outlined here should be expanded by instructors. (For more detailed laboratory directions than can be given here, reference should be made to the many excellent handbooks of zoölogical and botanical laboratory work, a few of which are mentioned in the brief bibliographies at the close of the chapters.)

In place of the ordinary index there will be found at the close of the book a *glossary-index.* In it are given brief definitions of all the technical words used in the book, with derivations and with page references. To make this more valuable as a reference glossary, some common biological words which do not chance to be used in the text are defined. These are easily recognized from the fact that they have no page numbers.

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CHAPTER I

THE SCOPE OF BIOLOGY

THE NEW BIOLOGY AND THE OLD

BIOLOGY is often described as the most recent of the sciences, despite the fact that it was one of the first to be studied. Four centuries before Christ, animals were dissected and described by Aristotle, and from that time on, the study of living things has never ceased. In the last half century, however, the study of vital phenomena has assumed a new aspect. Formerly animals and plants were studied only as objects to be *classified* and *named;* now they are studied as objects to be *explained.*

Progress of Scientific Thought.—This new method of biological study is only another expression of man's changed attitude toward all natural phenomena. In early times, people imagined that all the phenomena of nature which they could not understand were produced by gods. One god caused the winds; another the motions of the sun and stars. Gradually these conceptions have been changed by the attitude of modern science. First, the motions of the heavenly bodies were explained under the general law of gravitation. Then, the mysterious phenomena of fire and of electricity were comprehended under the laws of chemistry and physics. Later, the various changes on the earth's surface, such as the formation of mountains, of valleys, of rivers, and of plains, were explained as the result of the ordinary forces of nature.

In all this there has been a progress in one direction, namely, toward the explanation of natural phenomena by natural forces. The most recent of the natural phenomena to be studied with this end in view, are those associated with living

animals and plants. The question whether the activities of animals and plants can be explained by the same forces found elsewhere in nature, and the attempt to answer this question in the affirmative, form the basis of the new science of biology. Modern biology is thus something more than the study of animals and plants as dead objects to be collected, named, and classified. It is a study of animals and plants in action; as living beings to be related to their environment. It is this attempt to *explain life processes* which may be said to have raised biology to the rank of a new science.

THE FUNDAMENTAL PROPERTIES OF LIVING THINGS

Distinction between the Living and the non-Living.—Since biology (Gr. *bios* = life + *logos* = discourse) is the science of living things, we must first ask how living things may be distinguished from non-living. While it is a comparatively easy matter to recognize the distinction, it is difficult to draw it sharply. Indeed, some biologists are of the opinion that no rigid line can be drawn, and that there are some states of matter which are halfway between the living and the non-living. Whether or not this be so, it certainly is true that between most forms of matter which we call alive and those which we call non-living, there is a marked and recognizable difference, although it may be difficult to define it accurately. Four or five fundamental properties are characteristic of life:

1. **Activity.**—The most noticeable difference between the living and the non-living is in the presence or absence of **spontaneous activity.** If we wish to find out whether any given body is alive, we watch it carefully to see if it shows any power of independent activity, and if it does so, we call it alive. If the object, a seed for example, seems to be perfectly dormant, we may put it under conditions in which, if alive, it will develop activity. If it then begins to grow into a plant we say that the seed was alive at first but dormant. If, however, it fails to show any power of developing into a plant when placed

in proper conditions, we conclude that the seed is not alive. Hence the best criterion that we have for separating the living from the non-living is to determine whether or not the body in question either shows any signs of independent activity or, when put under proper conditions, may be made to show any signs of such activity.

Automatic activity.—The simple fact of showing activity is, however, not enough to serve as a criterion of life. Other things besides living beings have the power of activity. A watch, or a locomotive, or a steam engine certainly shows activity, and yet none of these is alive. There is, however, one distinction between the activity of such machines and the activity of a living organism. Machines show activity only when they are started into action by some outside influence; while a living organism develops activity from its own internal, independent power. With this modification, the first criterion that we have for distinguishing the living from the non-living is the power of developing **automatic activity,** and only objects possessing this power do we speak of as being alive.

2. **Death.**—The fact that living things show *automatic activity* has a converse side. This activity may cease, the object losing its power of showing *spontaneous activity.* This constitutes the phenomenon spoken of as *death.* To define either life or death has proved a puzzle to both science and philosophy. For our purpose, however, they can be fairly well defined as follows: By **life,** we mean the possession of the power of showing *spontaneous, automatic activity;* by **death,** we mean the *disappearance of this power.* Why an animal or plant, when it dies, loses this power, we do not know. In some cases it is undoubtedly because the complicated machinery which composes the body is injured and consequently cannot work properly. This we find true also in the case of ordinary machines. If a locomotive should burst its cylinders, it would no longer be able to run. If a watch has its mainspring broken,

it is thrown out of adjustment and consequently does not show activity. So in regard to living things; the inability to show further activity may undoubtedly be attributed to the fact that the machinery is out of order. If, for example, the beating of the heart ceases for any length of time, life activity must cease, because life activity is dependent on the circulation of the blood. Thus, in many cases we know positively that death comes from the breaking down of the machine. Whether death means anything more than the breaking down of the machine; whether anything is lost which can be called the *life force*, is one of the questions over which philosophy and biology have puzzled for long years, and upon which they have not reached any definite conclusion.

3. **Growth.**—All organisms *disintegrate* by oxidation and waste. When a piece of wood reaches the required temperature to unite with the oxygen of the air, it burns. Waste products appear as gases and ashes, and the wood disappears. In a similar way, by union with oxygen the living body is being constantly converted into waste products which are given off from the body as excretions. As a result the organism is constantly disintegrating. This would inevitably result in the disappearance of the organism if it were not for the opposite power of reintegration, or **growth.**

All living things have the power of growing, and no object that is not alive has this power. It is true that, under some circumstances, crystals may increase in size, and this is sometimes referred to as a growth of the crystals; but it is a totally different kind of growth from that which we find in living things. In the case of the crystal, the new material is simply laid upon the outside of the old, layer after layer, and the apparent growth is really an increase in size, by the process of accretion. In the growth of the living organism, material is taken inside of the body, and there it is transformed into compounds like those of the living organism which has absorbed it. Thus the living organism increases from within,—

a type of growth spoken of as intussusception (Lat. *intus* = within + *suscipere* = to take up). With this understanding of growth we can state that nothing grows except living things. As the result of their activities, living things are constantly wasting away; but by growth they repair and keep pace with their own wastes and remain in a practically constant condition, in spite of their ceaseless activity. In time, however, the disintegrating tendencies surpass the powers of repair, and the organism dies of old age.

4. **Reproduction.**—The power of **reproduction** is found only in the realm of the animate world, for only a living organism can produce another like itself. Inanimate things cannot reproduce their kind.

As a result of this power of reproduction, held in common by all things possessed of life, there is a constant replacement of the individual, a constant wearing out and death, a constant rebirth and growth, the new organism ever replacing the old as it disintegrates and disappears. There is a constant tendency to undergo *cyclical changes* present in all manifestations of life.

5. **Consciousness.**—**Consciousness** is characteristic of some living bodies, but is probably not universal among them, for it is practically certain that life occurs in many places without consciousness, although some theorists have endeavored to argue that all forms of life, even the plants, have a very dim form of consciousness. This is very doubtful, and we cannot regard consciousness as universally characteristic of life. Wherever consciousness is found, however, it indicates the presence of life, and thus may be deemed one of the most important signs of life.

CHEMICAL COMPOSITION OF LIVING TISSUES

Chemical Elements in Living Tissues.—Although there is a large variety of chemical compounds found in living animals and plants, nevertheless there is a certain uniformity among them. All animals and plants are made up primarily of a small num-

ber of elements, nine **chemical elements** being ordinarily pr
ent in living things, four of which predominate, while the oth
four are present only in small quantities. They are as follows:

Oxygen, a colorless, odorless gas, forming about one-fif
of the atmosphere.

Carbon, a solid at ordinary temperatures. Charcoal, graphi
lampblack, and diamond are examples of almost pure carbo

Hydrogen, a gas, the lightest of all known substances a
highly inflammable.

Nitrogen, a colorless, odorless gas which comprises abo
four-fifths of the atmosphere.

Sulphur, phosphorus, calcium, iron, and **potassium** cons
tute the other chemical elements that are found in livi

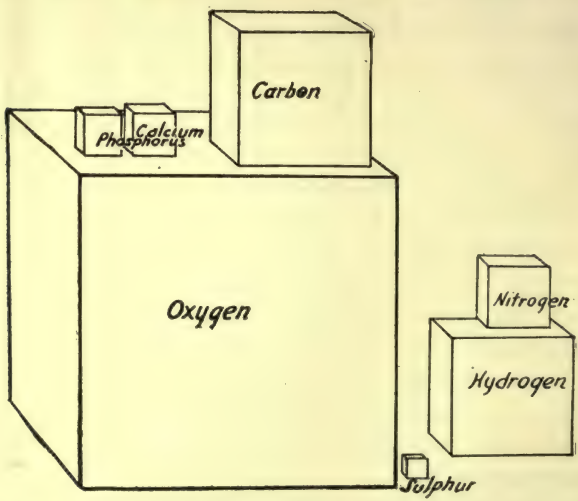

FIG. 1.—DIAGRAM SHOWING THE RELATIVE PROPORTIONS OF THE CHIEF ELEMENTS MAKING UP A LIVING BODY

things. Only very small amounts of these elements are prese
although calcium is found in animals in considerable quantit
in the bone. Figure 1 shows diagrammatically the relati

proportions of the chief chemical elements in the animal body. Oxygen, carbon, hydrogen, and nitrogen constitute about 98 per cent of the animal body and not far from the same proportion of the composition of the body of most plants. These four elements also constitute by far the largest proportion of the material present in the earth's crust; so that the living body is made of the same materials that are most abundantly present in the inanimate world around us.

Chemical Compounds in Living Tissues.—It is perfectly evident that the elements enumerated do not exist in the living body as uncombined elements. Two or more of them are always united as chemical compounds to form a substance different from either of them. The chemical compounds that are present in the bodies of animals and plants are of an endless variety; but a few general types are most widely present and may be regarded as the fundamental compounds of living things. These compounds are important, since they enter into the food of all animals. They are as follows: **proteids, carbohydrates, fats.**

Proteids.—Proteids are extremely complex substances, composed chiefly of the elements: carbon, oxygen, hydrogen, and nitrogen, but containing also in small proportions sulphur and the other elements that have been enumerated above. They are by far the most complex substances in living things; that is, in a proteid molecule, there are present more chemical atoms than are found in a molecule of any other substance existing in the animal body. The exact chemical composition of proteids is not known and it suffices for our purpose to state, that they are composed of a highly complex combination of the elements we have mentioned, so united that hundreds of atoms are probably always combined to make a molecule. Some idea of their complexity may be obtained from the fact that one chemist gave as a formula for egg-albumen, $C_{204}H_{322}N_{52}O_{66}S_2$ (a formula too complicated to have any real meaning); and indeed, no two chemists agree upon the chem-

ical composition of any proteid. The following are the best-known proteids: *albumen*, the white of an egg; *myosin*, the lean part of the meat; *casein*, the curd of the milk; *gluten*, the sticky substance in flour; *legumen*, a similar sticky material present in peas and beans. Besides these, there are many other proteids present in animal and plant tissues. Living tissue is almost entirely proteid in character.

Sources of proteids.—Since living things are made up largely of proteids, we next inquire into the source of these proteids. As will be noticed later, green plants can combine the gases of the air with the water and certain minerals obtained from the soil, and thus manufacture their own proteids. Animals and colorless plants (*fungi*) are totally unable to manufacture proteids from inorganic compounds. Hence it follows that animals and the colorless plants depend upon the green plants for their proteids, which is simply another way of stating the fact that animals require plants for their food. Although unable to manufacture proteids, colorless plants and animals are, however, able to modify them more or less, having the power to transform one kind of proteid into another. If, for example, an animal is fed with the white of an egg, it can transform this proteid into the proteid of muscle, thus changing albumen into myosin. Since animals are unable to manufacture muscles from any substances but proteids, it follows that they are obliged to have proteids in their diet.

Carbohydrates.—*Starches* and *sugars* are the best-known examples of carbohydrates. They are much simpler than proteids, consisting of only three chemical elements: carbon, oxygen, and hydrogen. These elements are combined in molecules with the following formulas: $C_6H_{10}O_5$ (*starch*) and $C_6H_{12}O_6$ (*sugar*). There is quite a large number of starches and sugars, differing from each other in some respects, but these formulas are typical of their general nature. It will be seen from the formulas that the difference between the molecules of starch and sugar is in the presence, in sugar, of H_2O in addition

to the group contained in the starch molecules. H_2O is a molecule of water; and hence we say that if a molecule of water is added to a starch molecule, it will convert it into a sugar molecule. It must not be understood, however, that this can be done by simply adding water to starch, for the two will not combine. There are methods (see page 306), however, by which they can be made to combine, and under these circumstances starch can very easily be converted into sugar.

Among the different types of sugars, there are two of especial importance. One of these is *grape sugar*, also called *glucose* or *dextrose.* These three names are closely related, although not exactly identical. The formula for these is also $C_6H_{12}O_6$. The other type is *cane sugar*, obtained from sugar cane or the sugar beet. The formula for this is $C_{12}H_{22}O_{11}$, which, as will be noticed, is nearly, but not quite, twice the formula of the grape-sugar molecule. By the addition of a molecule of water it is possible to break a molecule of the cane sugar into two molecules of the grape-sugar type, according to the following equation: $C_{12}H_{22}O_{11} + H_2O = 2C_6H_{12}O_6$. This is commonly spoken of as **inverting** the sugar.

Sources of carbohydrates.—Carbohydrates come almost wholly from the vegetable world. Green plants manufacture starch in their leaves by combining the carbon dioxid gas which they absorb from the air with the water which they absorb from the soil. This starch is very easily converted into sugar within the plant, and then carried to various parts where it may be stored, either in the form of starch or sugar. It is subsequently used by the plant as food, or, if the plant is consumed by animals, it serves as their food. So far as known, there is no other source of carbohydrates in nature besides the green plants, and as all animals and all plants consume carbohydrates, it is plain that the whole living world is dependent upon the green plants for carbohydrates.

Hydrocarbons (Fats).—Good examples of fats are found in butter, in mutton tallow, in lard, in olive oil, etc., and in many other

food products. Fats contain the three elements, carbon, oxygen, and hydrogen, in this respect agreeing with the carbohydrates. They are, however, considerably more complex than carbohydrates, a molecule of fat containing more atoms, as is shown by the formula $C_{51}H_{104}O_9$, which represents a common fat. When treated by a simple chemical method, fats are broken up into two substances, one of which is called *glycerine* and the other a *fatty acid*.

Sources of fats.—Fat can be manufactured by either animals or plants out of other foods. If an animal is fed upon proteids or carbohydrates, it can manufacture fat from them; and plants are able to make fat out of the food materials which they absorb from the air and water.

The table on page 11, which illustrates the composition of a few of our common foods, shows that our ordinary diet contains a fair proportion of each of these three foodstuffs. It will also be seen from this table that the largest proportion of proteids comes from animal foods, while the largest proportion of carbohydrates comes from plant foods.

ORIGIN OF LIFE

Perhaps no feature of modern biology is more important than the acceptance of the theory that every living thing comes from a living source. All living animals and plants with which we are familiar to-day have originated from previously existing life. The living animal comes from the egg that was produced by another living animal; the plant comes from a seed that was produced by another living plant. But the question of the *primal* origin of life is sure to intrude itself upon our minds, and we are forced to ask whether living things can be, or ever have been produced by any other means. Did there ever occur, or does there occur in the world to-day, a *spontaneous generation* of life? In other words, did a living thing ever arise from some source which was not alive? So far as our knowledge of nature is concerned, there are no means of starting new life except from previously existing life.

***TABLE SHOWING THE APPROXIMATE COMPOSITION OF FOOD PRODUCTS**

MATERIAL AS PURCHASED	REFUSE PER CT.	WATER PER CT.	PROTEIN PER CT.	FAT PER CT.	CARBO-HYDRATE PER CT.
Beef, sirloin steak	12.8	54	16.5	16.1	
Beef, round	7.2	60.7	19	12.8	
Chicken	41.6	43.7	12.8	1.4	
Pork, loin chops	19.7	41.8	13.4	24.2	
Pork, smoked ham	13.6	34.8	14.3	33.4	
Pork, salt		7.9	1.9	86.2	
Fish, cod	29.9	58.5	11.1	.2	
Oysters		88.3	6.0	1.3	3.3
Eggs	11.2	65.5	13.1	9.3	
Milk		87	3.3	4	5
Milk, skim		90.5	3.4	.3	5.1
Cheese, Cheddar		27.4	27.7	36.8	4.1
Butter		11	1	85	
Entire wheat flour		11.4	13.8	1.9	71.9
Wheat flour		12	11.4	1	75.1
Macaroni		10.3	13.4	.9	74.1
Oat breakfast food		7.7	16.7	7.3	66.2
White bread		35.3	9.2	1.3	53.1
Beans, dried		12.6	22.5	1.8	59.6
Peas, dried		9.5	24.6	1	62
Potatoes	20	62.6	1.8	.1	14.7
Apples	25	63.3	.3	.3	10.8
Bananas	35	48.9	.8	.4	14.3
Chestnuts, fresh	16	37.8	5.2	4.5	35.4
Peanuts	24.5	6.9	19.5	29.1	18.5
Chocolate		5.9	12.9	48.7	30.3

*From Atwater. Farmers' Bulletin No. 145. U. S. Dept. Agri. 1902.

Spontaneous Generation or Abiogenesis.—This idea of **spontaneous generation, or abiogenesis** (Gr. *a* = without + *bios* = life + *genesis* = generation), has been before the scientific world for centuries. The ancients in the time of Aristotle, and for centuries later, had no especial question in regard to the matter, and took it for granted that living things did come from inanimate matter. Virgil tells us of bees coming from the flesh of bullocks; Ovid recounts that slime begets frogs; and many centuries afterwards, we read that water produces fishes and that mice can come from old rags. Although to-day these ideas seem nonsensical, once they appeared perfectly logical.

Experiments of Redi.—This idea that life could come from non-living matter was held without question during the earlier centuries, and indeed until about the 17th century. In 1680 an Italian named Redi made an observation which led him to what was at that time a rather startling conclusion. It had previously been observed that fly maggots made their appearance in decaying flesh, and it was taken for granted that they developed spontaneously. Redi noticed flies hovering over meat, and demonstrated by experiments that if the flies were kept away by simply tying paper over a bottle containing the meat, maggots could never develop in it. A little further study proved that the flies laid eggs on the meat which developed into fly maggots. From this observation he drew the far-reaching conclusion that spontaneous generation did not occur and that all living things came from living ancestors.

This conclusion started a dispute which lasted for two centuries and was not fully settled until about 1875. For the conclusion of Redi, that all living things came from living ancestors, was vigorously disputed by the adherents of the old idea that life could arise spontaneously. Many ingenious experiments were devised to settle the question. It did not take long to prove that so far as the larger animals and plants were concerned, the conclusion of Redi was correct. But just at this time the newly invented microscope was beginning to

show a world of invisible life, and in the various bottles and flasks used in these early experiments, a large number of microscopic forms of life appeared in spite of all attempts made to prevent their entrance. Although in a piece of meat no fly maggots developed unless flies had previous access to the meat, innumerable microscopic forms of life did appear in it, in spite of all efforts to exclude them, even when the meat was carefully and hermetically sealed. Some of the early experimenters naturally concluded that these microscopic forms of life appeared spontaneously, while others insisted that these little organisms had found entrance into the sealed vessels from the outside, in spite of all precautions taken to keep them out. Great ingenuity was shown in devising experiments for settling this question. The results obtained by different experimenters were in great conflict for over two centuries, and apparently equally good evidence was found both for and against the belief in spontaneous generation.

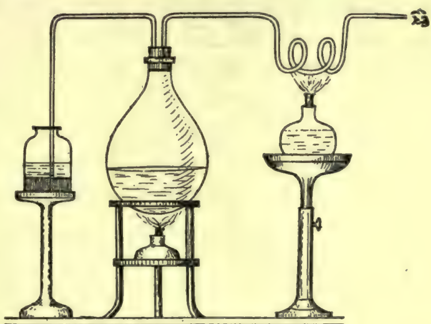

Fig. 2.—Apparatus used by Schwann in experimenting on spontaneous generation

Steam produced by boiling passed out through the tube, but upon cooling was drawn in again through the heated coil, which sterilized it.

Needham and Spallanzani.—The general method used by the experimenters was to place meat, hay infusions, cheese, etc., in flasks, and then by boiling to attempt to kill all life in the material, and later, by sealing hermetically, to guard against the entrance of any form of microscopic life from without. But even under these conditions it was frequently found that microscopic life made its appearance in the sealed vessels; Fig. 2. It proved very difficult *to be sure that nothing was left*

alive in the material after boiling,—i.e., that it was *sterile*, — and *to be sure that the sealing was effectual.* Two names especially connected with this dispute were Needham, in 1749, and Spallanzani, in 1777. Needham believed firmly in spontaneous generation, while Spallanzani insisted that the microscopic organisms that appeared in these experiments were either there originally and not killed by the boiling to which the material had been subjected, or had found their way into the solutions through microscopic cracks left by the imperfect sealing.

Pasteur and Appert.—In the middle of the last century the French scientist, Pasteur, carried out a series of experiments and attained results which conclusively disproved the theory of spontaneous generation. But the long debated question would not be settled even then. It is a curiously interesting fact that, while scientists were disputing over this matter, the question had, for practical purposes, actually been settled by Appert, who in 1831 had discovered the method of preserving animal and vegetable foods by the means of heat and sealing,— the method used by the canning industries of the present day. But the significance of this practical discovery was not appreciated, and the dispute continued even after Pasteur's work, the advocates of spontaneous generation continuing as insistent in their claims as ever. The settlement of the question was not reached until the English physicist, Tyndall, devised a new and ingenious method of experimenting which so satisfactorily guarded all sources of error that criticism was silenced. Indeed, so convincing were his experiments that his conclusions have practically never been questioned.

Tyndall's Experiments.—Briefly, Tyndall's method of experimenting was as follows: An airtight box was constructed, rectangular in shape and provided at either end and in front with glass windows. Into the top of this box passed small glass tubes which had been thrown into several curves, through which the air was allowed to enter freely; Fig. 3 *a*.

Recognizing that the great source of error in these experiments was due to the germ-bearing dust of the air, Tyndall attempted to free the air from dust by coating the inside of the curved tubes with glycerine, to entangle the dust particles of the air as it passed up and down the series of curves into the box. This method proved to be successful, for experiment and microscopic study showed that no dust passed beyond the second curve of the tubes. The interior of the box was also coated with glycerine, so that the dust particles which either settled to the bottom or floated against the side or top of the box would be caught in the glycerine. In this way Tyndall argued that he could obtain, in time, air perfectly free from germ-bearing particles.

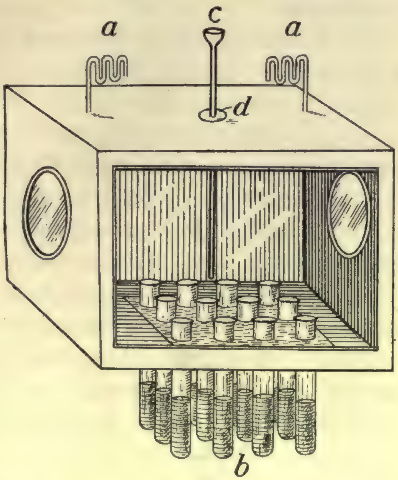

FIG. 3.—APPARATUS USED BY TYNDALL
For description see text.

He did not wish to begin an experiment until the air in the box was absolutely free from dust, and in order to determine this point the two glass windows at the end of the box were used. A ray of light was thrown through the box, in at one window, and out through the other. Thus, any dust particles that remained floating in the air of the box would be illumined and made clearly visible through the window in front. At first there were many dust particles to be seen floating in the air; but after the box had remained quiet for several days, the ray of light was invisible as it passed through the box, proving that no floating dust particles were present to be illumined. When this condition was reached Tyndall assumed

that the air was sterile, that is, pure, so far as any floating particles were concerned, and that his box was ready for experiment.

At the bottom of the box were a series of tubes whose mouths opened into the box but whose lower ends projected below; Fig. 3 *b*. By means of the long tube, *c*, which could be moved to and fro (since it passed through a rubber diaphragm, *d*), all the test tubes could be filled successively with any of the solutions with which he wished to experiment. In these tests, Tyndall used various materials: old meat, old cheese, hay infusion, etc., besides many other substances that previous experimenters had used in their attempt to settle the question. After filling the tubes with these various materials, they were heated to a temperature sufficiently high to destroy all life that they might have contained in the beginning. This was easily done, since the lower end of the tubes projected below the level of the box and could be very easily put into a bath of oil or brine, and heated to any desired temperature. Any steam or vapor that might arise from the open end of the test tube would pass into the box and readily find exit through the glass tube at the top. Upon cooling, a fresh supply of air would be drawn back into the box through the curved tube *a*, but, as already indicated, no dust particles would find entrance. Having thus, by heat, killed any living organisms that might be in the solutions to be tested, he again set the boxes aside and watched day by day to see what would happen. Since everything was clearly visible to the eye, it was possible to determine very quickly and surely whether any living organisms developed in the test tubes.

Tyndall's care in his experiments was so great that they were quite beyond criticism. His experiments showed the cause of previous errors and explained why there had been such conflict in the earlier experiments. He demonstrated among other things that some forms of life, called *spores*, might remain alive in boiling water for some time. This conclusion had been

previously reached by others; but Tyndall proved definitely that while a temperature below boiling is sufficient to kill active germs, the spores stand a temperature of boiling for a long time, and hence boiling does not sterilize liquids. Since previous experimenters had assumed that all life was destroyed by boiling, they had been contented with the simple boiling of the liquid to eliminate any organisms that might have been there originally. If, therefore, any of these resisting spores chanced to be in their solutions, they would subsequently develop; and from this fact the experimenter might reach the erroneous conclusion that the living organisms coming from these spores developed spontaneously. Tyndall carefully eliminated all of these errors and established the following important conclusions. *No evidence for spontaneous generation exists* and the success of an experimenter in obtaining any evidence of spontaneous generation is in inverse proportion to the care with which he performs his experiments.

This statement has stood almost unquestioned by biologists since it was first promulgated in 1875; and during the last thirty years the work of thousands of experimenters in the science of bacteriology has only confirmed the accuracy of Tyndall's conclusion.

We must accept the fact that whenever any living animal or plant, no matter how small, makes its appearance in a solution, originally there was present in this solution a living germ which started the development of the organism by the process of ordinary reproduction and growth. At the present time, therefore, there is no shred of evidence that, under any conditions which we can produce, life can arise spontaneously.

The Primal Origin of Life.—The conclusion that spontaneous generation does not occur to-day, leaves unanswered the question of the primal origin of life. It has been a disappointment to biologists to be obliged to admit that they can find no evidence for the theory of spontaneous development, since at some period in the history of the world, life must have made its

appearance for the first time. In an early period of the world's history, the earth was a hot, molten mass, and under these conditions no living matter could exist. It follows, then, that life must have made its appearance after the earth had sufficiently cooled. Biology, in endeavoring to explain life by natural forces, has been eager to believe that in these earlier conditions of the world the first living thing may have appeared as the result of natural law. The fact that biologists have almost universally accepted Tyndall's conclusion that no evidence for spontaneous generation exists, is thus a testimony, both to the truth of this conclusion and to the honesty of the scientists who have accepted it. They would have much preferred a conclusion of the opposite kind. The majority of biologists, however, believe it to be logically necessary to assume that at some time in prehistoric ages, the first living thing appeared from a source which was not living. While accepting the fact that abiogenesis does not occur at the present day or under present conditions, biologists still claim that we have no means of knowing what may have occurred under different conditions in earlier eras of the world's history. Thus, the problem of the primal origin of living matter still remains unsolved.

THE BIOLOGICAL SCIENCES

Since the science of biology deals with all living matter, it might broadly be defined as *the study of life in all its phases*. With this comprehensive definition, biology can be made to cover nearly the whole field of human knowledge — most sciences and even philosophy — including not only everything which relates to the life of man, but all that concerns the life of the animal and plant world as well. But for practical convenience in study, the field of biology is usually restricted to a group of definitely related sciences,— the so-called **biological sciences,**— and although within this group there are to be found many ill-defined boundary lines, and much overlapping and division

into sub-groups, the sciences which compose it may be enumerated as follows: **morphology,** with its sub-groups: anatomy, histology, taxonomy, distribution, structural embryology; and **physiology,** with its sub-groups: physiology proper, functional embryology, psychology, ecology, and sociology. (See reference chart, p. 21.)

MORPHOLOGY

Morphology (Gr. *morphê* = form + *-logia* = discourse) is that branch of biology which deals with the structure and form of animals and plants. It may be divided into five sub-heads:

1. **Anatomy** (Gr. *ana* = up + *temnein* = to cut) is the study of all of the grosser structure of animals and plants, that can be seen and dissected without the aid of the microscope.

2. **Histology** (Gr. *histos* = a web + *-logia*) is the study of the minute structure of animals and plants which is disclosed only by the aid of the microscope. It is sometimes called *microscopic anatomy* and deals chiefly with cell structure.

3. **Taxonomy** (Gr. *taxis* = arrangement + *nomos* = law) is the study of the relations of the organisms to each other and includes the classification of species.

4. **Distribution** is the study of the geographical distribution of organisms at the present time, and also their distribution in the past as disclosed by geology; to the latter study is given the name *paleontology*.

5. **Embryology** (Gr. *embryon* = an embryo + *-logia*) is the study of the development of the organism from the egg to the adult life. It is also called *ontogeny* (Gr. *on* (*ont*) = being + *-geneia* = producing) in distinction from *phylogeny* (Gr. *phylon* = race + *-geneia* = producing), the development of the race.

PHYSIOLOGY

Physiology (Gr. *physis* = nature + *-logia*) is the study of the activities or functions of organisms. Its scope may be best understood by its division into sub-heads:

1. **General physiology.** Physiology deals primarily with the functions of the different organs. Correctly used, it should include the functions of all animals and plants. Since, however, human physiology has been so much more studied than that of other animals, the term *physiology* usually refers to mankind. When the study extends to other animals or to plants, it is designated respectively as *animal physiology* and *plant physiology.*

2. When **embryology** concerns itself with the *activities* of the embryo, it then belongs to the domain of physiology.

3. **Psychology** (Gr. *psyché* = soul + *-logia*) is the study of the functions of the brain. It includes not only the study of the human brain but the brain activities of other animals as well, under the term *comparative psychology.*

4. **Ecology** (Gr. *oikos* = house + *-logia*) is the study of the relations of organisms to their environment. This includes their relations to inanimate nature as well as to animate. The term *ecology* is now more widely applied in relation to plants than to animals. Ecology includes **sociology** (Lat. *socius* = a companion + Gr. *-logia*), which is the study of the interrelations of animals of the same species. This, however, is chiefly confined to the human race, the term *sociology* usually referring to mankind. There are, however, some animals like ants, bees, etc., that have social relations, and the term *sociology* might be extended to them.

ZOÖLOGY AND BOTANY

The general term **zoölogy** includes any of the biological sciences when studied in their relation to animals, and the general term **botany,** when they are studied in their relation to plants.

BIOLOGY

The science of living things

MORPHOLOGY
The science of form

Botany includes / *Zoölogy includes*

- **Anatomy**
  The study of gross·structure
- **Histology**
  The study of minute structure
- **Taxonomy**
  The classification of species
- **Distribution**
  The geographical and chronological relation of organisms
- **Embryology (structural)**
  The study of development from the germ

PHYSIOLOGY
The science of function

Botany includes

- **General Physiology**
  The study of functions of organs
- **Embryology (functional)**
  The study of the activities of the embryo
- **Ecology**
  The study of the relation of organisms to their environment

Zoölogy includes (all of the above, and also)

- *Sociology*
  The study of interrelations of animals of the same species
- **Psychology**
  The study of brain functions

LABORATORY WORK WITH ORGANIC COMPOUNDS

PROTEIDS

Albumen.—Separate a little of the white from the yolk of an egg and dilute with three times its quantity of water. With this solution make the following tests:

1. Place a little of the albumen solution in a test tube and boil, noting that a precipitate appears; that is, the albumen coagulates. Repeat this test, heating the albumen in a test tube in a water bath, determining, by a thermometer placed in the test tube, at what temperature the coagulation occurs.

2. Add a little strong HNO_3 to some of the albumen in a test tube. A precipitate appears. Boil, and the precipitate will turn yellow. Allow it to cool and add enough ammonia to neutralize the acid and it will turn a deep orange. This is known as the *xanthoproteic* test for proteids.

3. To a weak solution of albumen add a few drops of NaOH and a few drops of a 1% solution of $CuSO_4$; heat gently and the solution will turn blue if ordinary proteids are present, but if peptones are present it will show a reddish color.

Gluten.—Place some flour in a large piece of cheesecloth, and gathering up the edges of the cloth, wash thoroughly in a pail of water. Much of the bulk of the flour will wash away, but the gluten will finally be left in the cloth, as a sticky mass that will not wash out.

Remove a little of the wash water from the pail in a test tube and add a few drops of iodine to it. If it turns blue it will indicate the presence of starch.

Casein.—Add a little 2% HCL to a few c. c. of milk. A curd will form which can be separated from the liquid by allowing it to drain through cheesecloth. The curd is the proteid, casein.

Myosin.—Soak some chopped beef in cold water for half an hour; stir and filter through cheesecloth. Boil the filtrate, and a mass of myosin will appear, which was dissolved in the cold water but is coagulated by heat.

Fibrin.—This is a proteid formed from blood. It may be obtained by collecting freshly drawn blood and stirring it immediately with a piece of wire gauze for about ten minutes. A mass of fibrin will collect on the wire, and it will be found that the blood will not subsequently clot, the removal of the fibrin preventing it.

CARBOHYDRATES

Starch.—Rub up a little starch (potato starch is best) in an evaporating dish with a considerable quantity of water. Place a few drops in a test tube and add a little iodine solution. The starch will turn blue.

Examine a little of the starch water under a microscope. Sketch some of the starch grains. Make a thin section of a bit of potato with a razor and examine under a microscope, noting the starch grains. Add a little iodine solution and again examine with a microscope.

Boil the starch water over a flame. As it comes near to the boiling point the mass will become thick and pasty (starch paste), due to the bursting of the starch grains by heat. Place a little under the microscope and look for grains. Add to the paste a little iodine and it will turn a brilliant blue.

Test for Sugar.—Put a little glucose or dextrose in a test tube containing a considerable quantity of water. Add to this a few drops of weak H_2SO_4 and a few drops of NaOH; boil. The presence of sugar is determined by the appearance of a brownish red precipitate, which goes through a series of color changes, but finally remains as a brownish red sediment at the bottom of the tube.

FATS

One of the simplest tests for fat is to place the material in which the fat is supposed to be upon a sheet of common paper. The paper will be rendered transparent by absorbing the oil of the fat-containing tissue.

Fat Emulsion.—Fat has the property of being readily divided into minute particles which, when mixed with water, float in the liquid, forming what is known as an emulsion. Place a few drops of olive oil in a test tube half full of water. The oil will rise to the top of the water and appear as a clear yellowish layer. Put a finger over the mouth of the test tube and shake vigorously. The whole contents of the tube will turn a milky white, and upon being allowed to stand the milkiness will remain for a long time. Eventually, however, the fat again separates from the water. This milky appearance is produced by the fact that the fat has been divided into minute particles that float through the water and refract the light in such a way as to give a white color. This is called an emulsion.

Examine, under a microscope with a high power, a drop of milk, noting that it is an emulsion.

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CHAPTER II

CELLS AND THE CELL THEORY

ORGANISMS

One characteristic feature of living matter is that it is not indefinitely distributed around the world, but is always associated in distinct units or individuals. In other words, there is no life apart from individuals. These units always contain different parts, each with a distinct function. This is very evident among well-known animals and plants. The human body possesses a heart, a stomach, a brain; and a tree has roots, leaves, flowers, etc. These different parts are called **organs**; and because it possesses organs, a living being is called an **organism.** While it is true that practically all living things do have organs, some of the lowest are so small that no organs have yet been found in them, as for example, *bacteria;* see Fig. 7. It is probable, however, that these do have organs if we were only able to see them; at all events, the term *organism* is extended to all living things whether they possess evident organs or not.

From the word organisms is coined the adjective **organic,** that is, pertaining to organisms. Organic substances have been produced by living beings, while **inorganic** substances have no connection with living things. Bone, muscle, wood, sugar, coal, etc., are organic; while stones, water, and air are inorganic. Nearly all organic substances contain carbon and are capable of being burned, while inorganic substances usually contain no carbon.

THE CELL AS THE UNIT OF ORGANIC STRUCTURE

The slightest familiarity with the larger well-known animals and plants shows not only that they are made up of different organs, each with its definite duty to perform, but also that these organs are composed of different parts, each having its specific

function. The stomach has its muscles and its secreting glands; the foot has its muscles, bones, tendons, ligaments, nerves, etc. The different kinds of substance which form the organs are known as **tissues,** and usually each tissue contains only one kind of material and has but one kind of duty to perform. For example: muscles, bones, glands, nerves, and tendons, each represent a distinct tissue; each has its special function in the organ, and each is different from the other. Muscles have the power of contraction, bones are for support, etc.

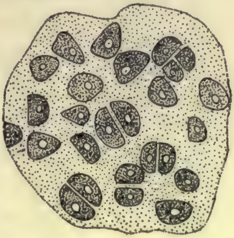


FIG. 4.— CELLS FORMING CARTILAGE TISSUE

By studying these different tissues under the microscope we shall find that they, too, are made up of minute parts, called **cells,** and that in most instances each cell is essentially like all the other cells of the same tissue. This may be shown by examining Figures 4 to 6, in which several kinds of tissue appear, each made

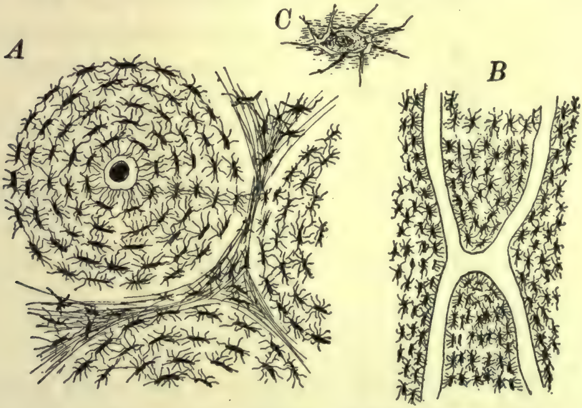


FIG. 5.—CELLS FORMING BONY TISSUE

up of a large number of independent, similar cells. These cells represent the ultimate units to which the analysis of the struc-

ture of living things has been carried at present; for while each cell is made up of parts, life as a whole seems to be found only where we have the whole structure of the cell developed. In other words, the cell is the simplest form in which life occurs, and is, in this sense, the ultimate unit of living structure. While an organ may contain many different kinds of cells, each tissue is, as a rule, made of but one kind of cell. The cells of the bone, for example, are all essentially alike, and so, too, are the cells of muscles and glands. The different cells in the same tissue may differ in shape and size; but these differences are only superficial; fundamentally the cells forming a single tissue are alike. Therefore, if we define a cell as the ultimate unit in the analysis of living structure, we may define a *tissue* as *an aggregate of similar cells, all having similar functions;* see Figs. 4, 5, and 6.

FIG. 6.—CELLS FORMING MUSCLE TISSUE FROM THE INTESTINE WALL

While the form, structure, and size of cells present an almost endless variety, in both the animal and plant worlds, nevertheless, all cells have in common certain general parts. Thus we may speak of the structure of a cell in general, recognizing that all living cells of both animals and plants, in spite of their differences, conform essentially to the type of an ideal cell.

CELL STRUCTURE

The description given below is not that of any particular cell, but rather that of a typical or ideal cell. Though a cell exactly like that described will not be found, it resembles closely the cell which forms the egg of certain animals, and in essential structure is like all cells found in animals and plants.

Structure.—The cell consists of four primary parts, some of which may be absent:—

1. **The protoplasm,** or *cell substance,* a liquid making up the bulk of the cell.

2. **The nucleus,** a rounded body within the cell substance.

3. **The centrosome,** a small body near the nucleus.

4. **The cell wall,** an outer covering which holds the cell substance. (The cell wall and centrosome are sometimes absent.)

Size.—There is much variation in the size of cells. Some of them are extremely minute. Bacteria, which are sometimes not more than 1/50,000 of an inch in diameter, are probably cells (Fig. 7), although we do not yet know positively that they contain a nucleus and centrosome. At all events the yeast, which is only a little larger than a bacterium (about 1/3000 of an inch), is a typical cell, possessing a nucleus, cell wall, and cell substance; see Fig. 32. At the other end of the scale we find giant cells,

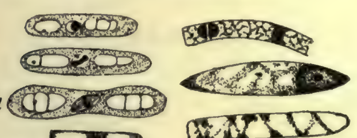


FIG. 7.—BACTERIA VERY HIGHLY MAGNIFIED

Showing the complex internal structure with bodies supposed by some to be nuclei. At *a* one cell shows what resembles karyokinetic division.

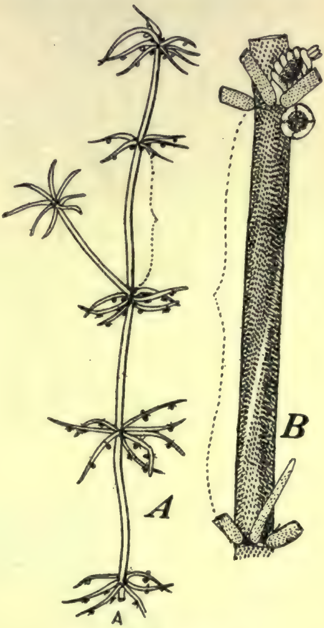


FIG. 8.—*NITELLA*

A, about natural size, showing nodes and internodes; *B*, one of the internodes more magnified. The part enclosed by brackets, between the two rows of leaves, is a single cell.

which may be an inch in length, as in the case of a small plant known as *Nitella* (Fig. 8), or larger still, as in the egg

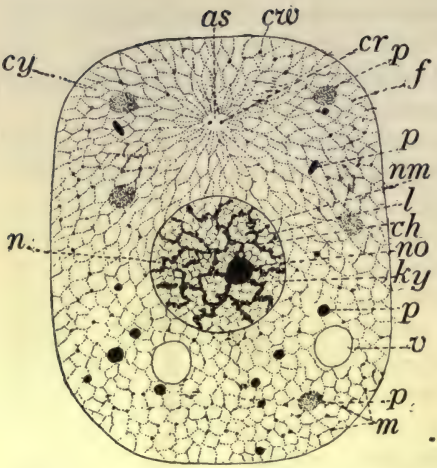


FIG. 9.—A DIAGRAM OF AN IDEAL CELL

as, centrosphere; *ch*, chromatin; *cr*, centrosome; *cw*, cell wall; *cy*, cytoplasm; *f*, fibers; *ky*, karyoplasm; *l*, linin; *m*, microsomata; *nm*, nuclear membrane; *n*, nucleus; *no*, nucleolus; *p*, plastids; *v*, vacuole.

of the ostrich, which is really a single cell. As a rule, however, cells are microscopic in size.

Shape.—A cell is usually more or less spherical (Fig. 9), although it may be distorted by pressure or irregular growth.

CELL SUBSTANCE OR PROTOPLASM

The material which composes the active part of the cell appears like a mass of more or less transparent jelly to which the name **protoplasm** (Gr. *protos* = first + *plasma* = substance) has been given. This material may fill the entire space within the cell wall, or lie in the form of a thin layer next to

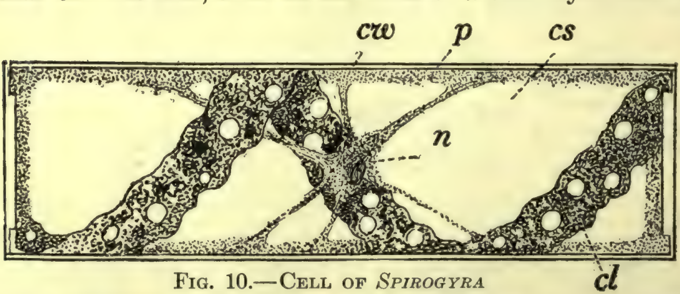


FIG. 10.—CELL OF *SPIROGYRA*

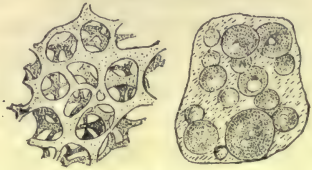
cl, cell chlorophyll; *cs*, cell sap; *cw*, cell wall; *n*, nucleus; *p*, protoplasm.

the cell wall, the rest of the space being filled by a watery liquid; Fig. 10.

Structure.—When protoplasm is examined under the microscope it is not found to be a homogeneous jelly, as was at first thought, but to have an intricate structure which is only partly disclosed by the microscope; Fig. 11. The exact structure of this cell substance has not been fully determined, and there are at least three different theories to explain its microscopic appearance.

The Reticular Theory.—One school of scientists describes protoplasm as an extremely minute network of fibers forming a sort of sponge, in the meshes of which there is found a moving liquid; Fig. 11 *A*. This is the so-called **reticular or fibrillar theory** of protoplasmic structure.

The Foam Theory.—Another school explains the appearance of protoplasm as due to a mass of minute bubbles, like soapsuds on a small scale; and insists that what appear to be fibers are only the delicate lines separating the bubbles from each other; Fig. 11 *B*. This is the **foam theory** of protoplasmic structure.



A *B*

FIG. 11.—DIAGRAMS ILLUSTRATING THEORIES OF PROTOPLASM

A, the Fibrillar; *B*, the Foam.

(Dahlgren and Kepner.)

The Granular Theory.—Still a third theory suggests that the protoplasm consists of an indefinite number of minute, living, moving granules, arranged in lines resembling fibers or in various other figures. This is the **granular theory** of protoplasmic structure.

Between these theories the scientists have not reached any conclusion, although the first two have been more generally accepted than the last. It is quite possible, and even probable, that all of the theories may have a certain amount of truth in them, and that protoplasm does not in all cases have the same structure. It is certain, however, that protoplasm always shows a structure and is not a homogeneous body. In most cases

two, and frequently three, distinct substances are discernible in it.

1. A meshwork (*reticulum*) resembling fibers.

2. A liquid (*cytoplasm*) occupying the meshes of the network.

3. Minute bodies (*microsomata*) (Gr. *micros* = small + *soma* = body) scattered along the branches of the network, regularly or irregularly, and frequently moving to and fro in the cell.

Activity of Protoplasm.—If living protoplasm be studied under the microscope, it will frequently show a type of motion called *streaming*. This is due to minute granules constantly circulating in a more or less definite or indefinite fashion within the cell. Whether all protoplasm will show such motion we do not know, but apparently whenever this substance is actually alive this motion is present. Possibly this may not be true of protoplasm that is known as dormant, but it is almost certainly true of all active cells.

THE NUCLEUS

Lying within the cell substance there is a smaller body, usually of an approximately spherical shape, called the *nucleus* (Lat. *nucleus* = nut); Fig. 9*n*. This is a structure of extreme complexity. It is, as a rule, bounded by a delicate nuclear membrane *nm*, which holds the contents and separates them from the surrounding cell substance. Within this membrane may be found a jelly-like mass, very similar to, if not identical with, the cell substance outside, and also included under the term *protoplasm*. To distinguish these two parts of the protoplasm, that inside of the nucleus is called **karyoplasm** (Gr. *karyon* = nut + *plasma* = substance) or *nucleoplasm*, while that outside is called **cytoplasm** (Gr. *cytos* = cell + *plasma*); Fig. 9 *ky* and *cy*. In addition to karyoplasm, however, there are other distinct parts in the nucleus. Delicate fibers run through it called **linin fibers** (Fig. 9 *l*), and a small rounded body known as the **nucle-**

olus (Fig. 9 *no*) is usually present and is sometimes very prominent. The significance of this nucleolus is at the present day unknown.

The most remarkable substance in the nucleus is a material known as **chromatin** (Gr. *chroma* = color); Fig. 9 *ch*. It has received the name chromatin from the fact that it has a special affinity for certain staining reagents, the chromatin material in the nucleus being the first thing to absorb the color and become stained. By special methods the chromatin may be stained and the rest of the nucleus left unstained. The latter is sometimes called *achromatin* (*a* = without + *chroma* = color). By this special process of staining it is possible to show the chromatin in prepared specimens, although in the living cell the chromatin

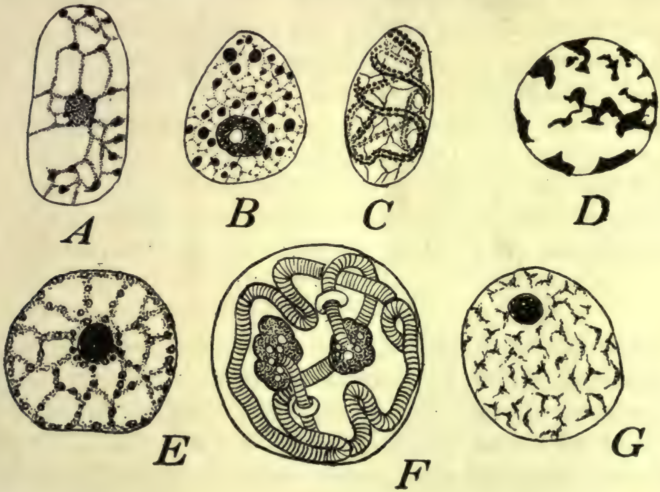


FIG. 12.—NUCLEI, SHOWING THE DIFFERENT APPEARANCES OF THE CHROMATIN (VARIOUS AUTHORS)

is so transparent as to be practically invisible. Chromatin occurs in a great variety of forms in different nuclei. Some of these are shown in Figure 12. It is sometimes diffused irregu-

larly through the nucleus; it may be in the form of stars, or a long coiled thread, or it may appear as isolated threads, or as threads interlaced, etc. Whatever its form, it always has the power of absorbing coloring material and is probably always of the same general, chemical composition. The nucleus controls the cell activities, and the chromatin forms the most important part of the nucleus.

THE CENTROSOME

Near the nucleus in many cells may be found a minute body (Fig. 9*cr*) known as the **centrosome** (Gr. *centron* = center + Gr. *soma* = body), which is usually present in the cells of animals, where it seems to have an important function in controlling the multiplication of the cell. The centrosome is usually lacking in the cells of the higher plants. Frequently two centrosomes are found near together, and sometimes they are surrounded by a clear area, which is designated as the *centrosphere.* At one time the centrosome was considered of great importance in the life of the cell, from its prominent rôle in cell division; but since it has been discovered that some cells have none, while others have several, its significance as an essential element in cellular structure has been doubted.

THE CELL WALL

One of the functions of the cell substance in many cells is to secrete around the cell a material of harder consistency than the protoplasm, the **cell wall.** Some cells have no cell wall; for example, the animal shown in Figure 13 is a cell devoid of a cell wall; and in many other animal cells the wall is either very slight or entirely lacking. From this, it is evident that the cell wall cannot be regarded as an essential part of the cell. In nearly all vegetable tissues, the living protoplasm secretes a membrane of greater or less consistency, and the same is also true of many animal cells. The cell wall may be made of a variety of different materials. In plants it is sometimes of wood,

or of a material allied to starch and known as cellulose. Again it may be composed of lime, or made up of a hornlike substance, as in the case of the cells that secrete the finger nails, or the horns of animals. The cell wall is not alive, being simply a secretion of the living cytoplasm. The cell walls may be very thin, or entirely absent as in Figure 13. In other cases they may be very thick and form a tissue principally composed of cell wall, with only scattered bits of living protoplasm in the midst of a great mass of secreted wall substance. This is especially true in the case of the cartilage, as shown in Figure 4. The shape of a cell is usually determined by the shape of its cell wall. Figure 14 shows a number of cells and gives an idea of the various shapes the cell wall may assume.

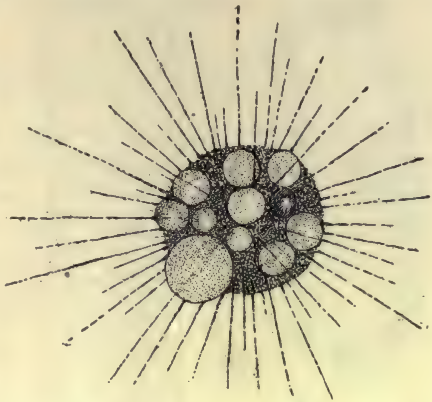


FIG. 13.—A SINGLE-CELLED ANIMAL *ACTINOPHRYS*
A cell without a cell wall.

Since the cell wall is lifeless and has only the function of support, the cell contents alone being alive, it follows that any organism may contain both living and lifeless material. Among plants the lifeless material may far surpass the living in bulk. In a tree, for example, most of the trunk, roots, and branches are made of the dead walls of cells which were formerly filled with living protoplasm. In a large tree only a thin layer of cells directly under the bark, the cells found in the leaves, buds, and some cells in the roots, are actually alive. In animals a much larger proportion of the body cells are alive, the bulk of the muscles being living protoplasm; but the skin, hair, cartilage,

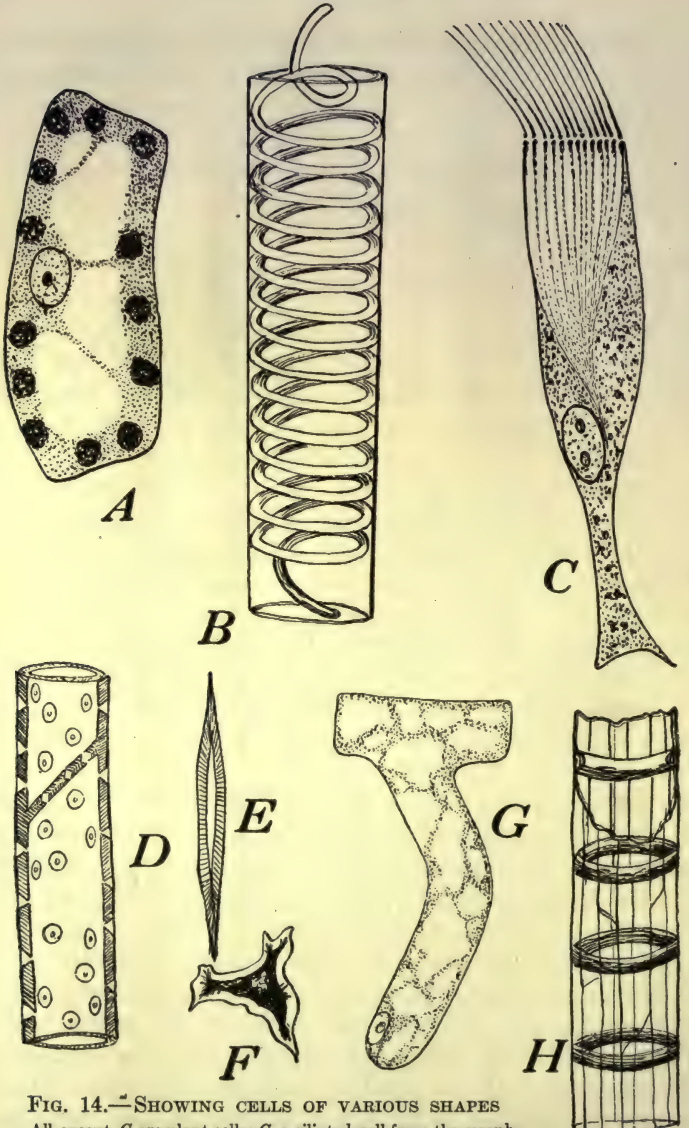


FIG. 14.—SHOWING CELLS OF VARIOUS SHAPES

All except C are plant cells; C, a ciliated cell from the œsophagus of an animal. (From various authors.)

and bone contain in a marked degree lifeless cell walls from which the living matter is either wholly withdrawn, as in the hair, or remains only in a relatively small amount, as in bone and cartilage.

Other Substances in a Cell.—Cells may contain other bodies than those already described, which cannot be regarded, however, as essential to cell life, since they are not characteristic of all cellular structure. Some of these are called **plastids** (Fig. 9 *p*), and seem to grow and divide and to be handed on from one cell generation to the next. Examples of such plastids are the *chlorophyll bodies* in plant cells, or *vacuoles* in some animals. Other bodies included in cells are purely passive bodies which seem to be functionless, inert, excreted substances, not growing and not handed down from generation to generation.

CELL FUNCTIONS

The cell with its protoplasm and nucleus contains all of the parts that are necessary for life, and, so far as we know, nothing simpler than a cell is capable of carrying on all the functions of life. If this be true, we are justified in saying that the ideal cell we have been describing is *the simplest bit of structural machinery that can manifest all the functions of life.* All living organisms, animals and plants alike, are either single cells (unicellular) or complexes of cells (multicellular), and the life of the organism as a whole is thus the combined life of its individual cells.

Definition of a Cell.—To sum up, then, we may say: *A cell is a combination of a bit of protoplasm (cytoplasm) with a nucleus,* and it is the simplest structure known to show the phenomena of life.

HISTORY OF THE CELL DOCTRINE

The development of the cell doctrine may, for convenience, be divided into three periods:—

1. The early conception of the cell, 1839 to 1861.

2. The discovery of protoplasm and the development of the mechanical theory of life, 1861 to about 1885.

3. The discoveries of the functions of the nucleus and its relations to reproduction and heredity, from about 1880 to the present.

While these periods are not sharply marked off from each other, they do represent different epochs in the development of the conception of the nature of the cell.

I. THE EARLY CONCEPTION OF THE CELL (1839-1861)

The Formulation of the Cell Theory, 1839.—It was not definitely proved until about 1839 that the tissues of animals and plants were composed of cells, although cells were first described in 1665 by Robert Hooke. A microscopic study of a piece of cork showed him that it was made up of large numbers of minute compartments which reminded him of the cells of a monastery. Hence he gave them the name of **cells,** which they still bear. Miscellaneous observations followed at intervals in the next two centuries. In 1833 Brown described the nucleus as a constant part of the cell. In the years 1838 and 1839 two Germans, Schwann and Schleiden, one studying animals and the other, plants, advanced the theory that the tissues of all animals and plants were made up of these independent units, to which they still gave the name of cells. These observations formulated the so-called **cell doctrine.**

The Original Conception of the Cell.—It was first supposed that the cell wall was the most essential part of the cell in controlling the processes of life and separating the contents of the cell from the surrounding medium. This conception did not last long, for it was soon seen that there were many cells that did not have cell walls. In these early days the existence of a nucleus was not realized as of much significance.

The Origin of Cells.—In the beginning it was supposed that cells were like crystals and developed from a *cytoblastema* as

crystals form in a supersaturated solution of sugar, the cytoblastema being described as a complex, supersaturated solution formed by the living body. This theory did not last many years, however, because it was shown that cells arise only from other cells. Even as early as 1846, Schultze and others proved that cells have no other origin except from previously existing cells. Starting with an egg, which is easily demonstrated to be a single cell (Fig. 15 *A*), and then carefully studying its development, it can be shown that its growth is by the method of repeated division and sub-division (Fig. 15 *B*, *C*, *D*, *E*, *F*) until the single-celled egg gradually becomes the many-celled adult. Although the cells become very numerous, they all arise by the process of division from the original egg cell. For many years, however, it was considered possible for a cell to arise in some other way than by division of the original egg cell; and even as late as 1880 discussions took place as to whether "free cell origin" was possible. By this term was meant the origin of cells from any source except from a previously existing cell. In time this question was settled in the negative, and we are now certain that cells never arise except from the division of earlier cells, and that all the cells of an adult animal body, though there may be millions, have arisen by the process of division from the original egg, which was in itself the single cell from which the life of the

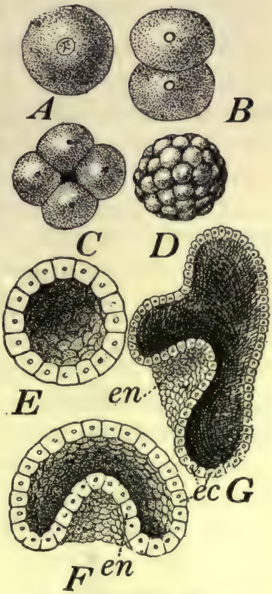


FIG. 15. — THE DEVELOPMENT OF THE EGG OF A SEA-URCHIN

Showing how a single-celled egg (*A*), by division (*B* to *G*), grows into a many-celled animal.

en, endoderm;
ec, ectoderm.

F and *G* show side folding inward to form what becomes the digestive tract.

individual started. Figure 15 shows how the single cell divides and continues to divide to produce the many cells of the adult organism.

2. PROTOPLASM AND THE MECHANICAL THEORY (1861-1885)

The Discovery of Protoplasm.—In 1839 Purkinje first recognized under the name "sarcode" the contents of the animal cell; H. Von Mohl in 1846 applied the term **protoplasm** (Gr. *protos* = first + *plasma* = substance or form) to the viscid, granular substance found in plant cells. Cohn in 1850 claimed not only the identity of animal and plant protoplasm but contended that it was the seat of vitality,—the basis of life. In 1861 Max Schultze established Cohn's theory and extended the meaning of the word *protoplasm* to include all living matter. This was a new conception and at once placed the doctrine of biology upon a new basis. If it could be proved that the cell substance, which is the living material in all cells, is always alike, it would show that life could be reduced to one fundamental basis. The name *protoplasm* had been given to the living substance in the animal embryo and then to a similar material in the cells of plants; but it was Schultze who identified it with the living material of animal cells and extended the name to apply to this universal life substance. With this new conception, he defined a cell as a *mass of protoplasm surrounding a nucleus*, and thus placed the keystone in the arch of the *protoplasmic theories.*

Schultze's conception of protoplasm was somewhat expanded and made more significant by Professor Huxley in 1866. Huxley, giving to it the name "physical basis of life," drew far-reaching conclusions as to the significance of the phenomenon that we call life, based upon this universal physical substance. He argued that the properties of life are simply characters of this protoplasmic substance, just as other properties are characteristic of water; and that life represents no distinct entity, but is simply a name applied to the combined properties of this remarkable chemical compound, protoplasm. This started

a long search for a chemical explanation of life phenomena. In accordance with this idea, life was looked upon as merely representing a special manifestation of chemical and physical forces; it was argued that there was no more reason to speak of *vitality* as a special property possessed by living things, than to speak of *aquosity* as a special property possessed by the chemical compound water.

The Mechanical Theory of Life.—Based upon this conception arose a large number of interesting speculations, and the discussions during the next twenty-five years resulted in a development of the **mechanical theory of life.** It was argued that, if life is merely a name given to the properties of protoplasm, and if chemists could manufacture the chemical substance protoplasm, they could thus create life, *i.e.*, living protoplasm. Chemistry was at this time advancing with prodigious strides, and chemists were making more and more complex substances, and new compounds which had hitherto been considered beyond their reach. Many of the substances, which had previously been supposed to be produced only by living processes, were, one by one, manufactured synthetically in the chemist's laboratory. From this the further assumption and confident prediction was made that the time would come when it would be possible to manufacture a bit of protoplasm by purely chemical means; and then it would follow, if the mechanical theory of life were correct, that this bit of protoplasm would necessarily be alive and scientists would thus be able to manufacture a living thing. This was the essence of the mechanical theory of life which largely dominated discussion of biology for a quarter of a century.

General Properties of Protoplasm.—With this idea of protoplasm as the basis of life, a large amount of study was given to this interesting material. Since it is alive, it has of course all the properties of life. If we look upon protoplasm as the physical basis of life, we may in one sense say that its properties are as varied as are the properties of living things, since the characteristics of living things are based upon the charac-

teristics of their protoplasm. If the characters of mankind are dependent upon the properties of its protoplasm, it follows that the protoplasm that makes up the cells in man must differ as much from the protoplasm that makes up the cells of a plant as mankind differs from the plant. There will be, then, as many varieties of protoplasm as there are varieties of living beings in the world. But apart from these detailed characters, we find that the substance protoplasm, using this term now to refer to the general life substance of the cell, has a few characteristics that are present in all forms of protoplasm whether animal or plant. In other words, all forms of living matter possess certain general properties, which are frequently spoken of as the **general characters of protoplasm.** They are as follows:—

1. **Chemistry of Protoplasm.**—Various attempts were made in earlier years to determine the chemical composition of protoplasm. The chemical elements out of which it is made are easily found to be *carbon*, *hydrogen*, *oxygen*, *nitrogen*, *sulphur*, and some other substances in small quantities. For a time it was supposed to be a definite chemical substance with a definite formula, and attempts were even made to give the number of atoms present in a molecule of protoplasm. We now know that such attempts were necessarily futile. Protoplasm is not a chemical compound but a mixture of a variety of different compounds. The fibrillar network, the liquids, the microsomata, and the chromatin are certainly all different from each other, and it is manifestly impossible to speak of the chemical composition of protoplasm as a whole. We can safely say that protoplasm contains proteids, but beyond this, little of significance has yet been determined. Since it is in a very unstable condition, constantly undergoing changes, its chemical composition cannot be constant. Moreover, the chemical nature of living protoplasm is doubtless different from the same material when dead, and since any chemical tests are sure to result in its death, it is impossible to determine the composition of the material when alive.

2. **Irritability.**—All forms of living protoplasm have the power of reacting when stimulated. This phenomenon is called **irritability** and is produced by the action of a large variety of external forces upon the protoplasm itself. Any external force which serves to produce a reaction in the protoplasm is spoken of as **a stimulus.** Almost any kind of stimulus has the power of affecting protoplasm: *mechanical, thermal, electrical,* and *chemical.* Stimuli all have their effect upon protoplasm and all produce certain **reactions** within it. Protoplasm is, in short, irritable to almost any external stimulus. While the different forms of protoplasm show different degrees of irritability to various stimuli, they have certain general reactions in common. The activity of protoplasm increases directly with the heat to a certain point, and then decreases, and finally ceases altogether if the temperature continues to rise.

Although some forms of protoplasm are much more irritable to *mechanical* stimuli than others, nevertheless, all types of protoplasm are influenced by external, mechanical force. Various other factors,—light, chemism, gravity, etc.,—mentioned upon pages 57, 58, stimulate protoplasm. Various organic, internal changes stimulate it as well. If the protoplasm is improperly nourished it produces a condition that is in general known as *hunger*, and this excites the irritability of protoplasm. The same thing is true if there is insufficient water within the protoplasm, producing an irritation called *thirst.* Protoplasm is also destroyed by various chemicals called *poisons*, like chloroform, corrosive sublimate, etc.

3. **Conductility.**—An irritation produced in any one part of a bit of protoplasm is rapidly conducted throughout the whole mass, a phenomenon known as **conductility.** In an ordinary cell, this phenomenon of conductility does not have very much meaning, because the bit of protoplasm is too small; but some cells possess long protoplasmic fibers extending from their bodies; and then this function of conducting impulses from one end of the protoplasm to the other becomes of considerable

importance. For instance, a nerve fiber, even in the higher animals, consists of a long bit of protoplasm extending from the cell body; see page 169. The phenomenon of conductility in this case is of great significance because it may carry an impulse from the outer end of these nerves (the periphery) to the cell body in the brain, or it may carry one that started within the body rapidly outward to the periphery. This phenomenon of conductility, therefore, forms the primary function of the nerves. It is this function that makes it possible for a stimulus applied to the outer part of the animal to be carried rapidly over the animal so as to produce a response in other parts of the body.

4. **Assimilation.**—All protoplasm has the property of taking in food material, changing its chemical nature and converting it into new protoplasm by assimilation; a process which may result in growth. This process is probably always a constructive one; *i. e.*, it builds more complicated materials out of simpler ones. Different kinds of protoplasm have this power developed to a widely different extent. Some cells assimilate and grow with great rapidity, with the result that they multiply rapidly; other cells seem to have lost much of this power of assimilation in their adult life, and are able only to replace the worn-out parts of their own structure. In the higher animals, for example, the cells are all capable of rapid assimilation, growth, and reproduction in youth, but many of them nearly or wholly lose this power after the animal has reached adult life. The nerve cells in the brain and spinal cord, for example, seem largely to have lost this property of assimilation, for they are unable to grow after they have once reached the adult form, although able to repair their own wastes. Later in life, nearly all the cells in the body lose this power, a condition characteristic of old age. Speaking generally, this power of assimilation and growth is most active at the very beginning of the life of a cell; it continues for a period with a gradually declining vigor and finally comes to an end, starting vigorously again as the result of the process of reproduction.

5. **Reproduction.**—Reproduction is the direct result of assimilation; for assimilation produces growth, and growth in the end results in division. All forms of reproduction take the form of division.

The four properties, irritability, conductility, assimilation, and reproduction, have been described as belonging to protoplasm; and the mechanical theory of life has centered around this conception. But in a sense it is misleading to call them properties of protoplasm, unless in the term *protoplasm* we include all of the contents of a cell, the nucleus as well as the cell substance. A living cell shows these general properties; but the living cell consists of protoplasm and nucleus, both of which are necessary in order that all the functions mentioned should be shown. The material frequently called protoplasm, *i. e.*, the substance outside of the nucleus, does not show all these functions. We ask, therefore: What are the functions of the nucleus and protoplasm as distinct from each other? To draw a sharp line between them is not possible at present.

3. THE NUCLEUS AND ITS SIGNIFICANCE (1880 TO THE PRESENT)

In the early study of the cell the nucleus was looked upon as an unimportant part, and in all of the early discussions its significance was generally neglected. From about 1880 the modern microscope and modern methods began to be directed towards the nucleus, and a series of marvelous and unexpected results were obtained, leading to the recognition of the nucleus as perhaps the most important part of the cell, and as possessing a structure of wonderful complexity and marvelous properties. The structure of the nucleus has already been outlined and may be seen in Figure 12. These figures are enough to disprove any idea that either cytoplasm or nucleoplasm can be considered a definite chemical substance. They indicate clearly that in the simplest life unit, we are not dealing with a homogeneous compound but with a complex structure and a mechanism of delicate adjust-

ment. This has been made even more evident and brought to a point beyond discussion by a study of the functions of the nucleus.

A nucleus is necessary to the complete life of a cell. Among the unicellular animals are some cells large enough for experimenters to cut to pieces in order to study the different functions of the fragments. These experiments are very difficult and delicate, but they have been carried on by a number of investigators independently, who have demonstrated the following facts: If a cell is cut to pieces in such a way that each piece contains a fragment of the nucleus, each fragment is capable of carrying on independently all life functions. Each can feed, grow, and

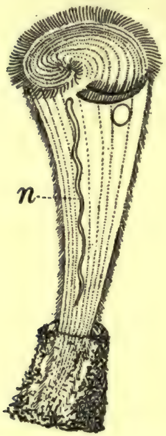


FIG. 16.—*STENTOR.* A SINGLE-CELLED ANIMAL; *n*, THE LONG NUCLEUS

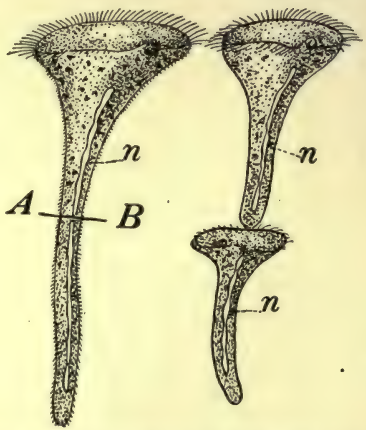


FIG. 17.—SHOWING HOW THE *STENTOR*, WHEN CUT INTO TWO PIECES ALONG THE LINE *AB*, DEVELOPS INTO TWO COMPLETE ANIMALS

multiply, and seems to be lacking in none of the essential functions of life; Figs. 16 and 17. If, however, the animal is cut to pieces in such a way that some of the fragments contain pieces of the nucleus, while others contain none, the frag-

ments act in totally different ways. Those that contain nuclear material are able to redevelop lost parts, to carry on their life processes and to grow and multiply as usual; the fragments that contain none of the nucleus, although they can move around and apparently maintain life for a while, are unable to feed, or at least to assimilate their food; they are unable to grow and unable to multiply; Fig. 18. They have thus lost the most essential features of life, since they have lost the constructive power by which protoplasm can assimilate and grow. These experiments, repeated many times over, show that the complete life of a cell is impossible without the presence of a certain amount of nuclear material, but if nuclear matter is present, the cell can carry on its complete life, even though the nucleus is itself cut into many pieces. Such experiments, of course, demonstrate very conclusively that life functions cannot be carried on by protoplasm alone, but only by protoplasm in combination with nuclear substance.

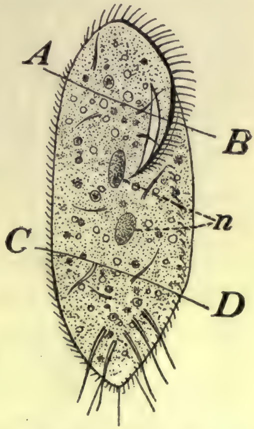


FIG. 18.—*STYLONYCHIA.* A SINGLE-CELLED ANIMAL

If cut along the lines *AB* and *CD*, only the middle piece contains any nuclear matter; this alone develops into a complete individual, the other fragments soon dying; *n*, the two nuclei.

The Nucleus in Heredity.—It is well to anticipate here one further fact that demonstrates the great significance of the nucleus and chromatin. As we shall notice on a later page, nearly all animals and plants show a form of reproduction in which cells from two different individuals, male and female, combine. This is known as **sexual reproduction** or **fertilization.** When this union takes place, it is not the whole cells that combine but only the nuclei; or still more accurately, it is the chromatin material of the cells that combines rather than the whole nuclei. The reconstructed cell contains chromatin ma-

terial from both of the cells which entered into the combination. Now inasmuch as, after this combination, the offspring which arises from the cell thus formed by the union of the two parental cells inherits characteristics from both parents, and inasmuch as the only part of the original sex cells which enters into the union is the chromatin, it follows that the chromatin material itself is the bearer of heredity, and that in these little chromatin threads, minute as they are, there must be a complexity sufficient to contain the features of inheritance that are handed on from generation to generation.

These facts give at least some idea of the separate properties of cell substance and nucleus. The cell substance by itself has the functions of irritability and conductility; but not of assimilation, growth, or reproduction. These latter functions can be carried on only when a nucleus is present.

WHAT IS MEANT BY PROTOPLASM

It has become evident by this time that the original conception of protoplasm has quite disappeared. Indeed, if we ask to-day just what is meant by protoplasm, the question becomes very difficult to answer. We can no longer look upon it as simply the jelly-like substance within the cell in which the nucleus lies embedded, for it is evident that although this substance has the properties of irritability and conductility, it does not have the properties of assimilation and growth. If we wish still to call protoplasm the physical basis of life, we must extend the term to include the nucleus as well as the substance outside of the nucleus, since without the nucleus, protoplasm is unable to carry on life processes. If, however, we include, in this term *protoplasm*, the centrosome, and the nucleus with its chromosomes, it becomes evident that protoplasm has quite lost its original significance. It is no longer the homogeneous substance, and can no longer be looked upon as a chemical compound, but is on the other hand a mechanism with a number of distinct, though closely correlated parts.

The explanation of its activities can no longer be regarded as a chemical problem simply, but must be in a measure a mechanical problem as well. This conception totally alters the significance of the phrase "the physical basis of life" and puts the problem of the mechanical theory upon a decidedly new footing.

To-day biologists are gradually giving up the use of the term *protoplasm* as confusing and misleading, replacing it by more definite terms which refer directly to the different parts of the cell. So now we find coming into general use the terms *cytoplasm* and *karyoplasm* (see page 32) to cover what was formerly called protoplasm. Both cytoplasm and karyoplasm are necessary and must act together in order to show the general characters of life. That reproduction may occur, the chromatin, and perhaps the centrosome also, are requisite.

The mechanical theory is no longer tenable in the form in which it was originally advocated and discussed. That position has been necessarily abandoned since the studies of more recent years have demonstrated that protoplasm is not a homogeneous substance and cannot be regarded simply as a chemical compound. It is, on the contrary, a very complex mixture of substances, forming a complicated machine in which the parts are most intricately interrelated and adjusted. While chemical forces may be regarded as sufficient to manufacture almost anything in the way of chemical compounds, they are not adapted to the manufacture of such a mechanism as living protoplasm has been proved to be. This change in the attitude of biologists has been brought about mainly through the minute study of the nucleus and the constantly increasing recognition of its great importance in the life of the cell.

Are There Life Units Simpler Than Cells?—As we have learned, the cell is by no means a simple structure but a complicated mechanism. The question inevitably arises whether the cell is the simplest structure that can manifest life or whether it may not be analyzed into simpler units. This is one of the puzzling and unsettled problems of biology. Certainly some of

the most minute living things (certain bacteria) seem to possess a body in which there is no definite nucleus, but in which the chromatin matter is more or less scattered without being aggregated into a nuclear mass, and this has led to the suggestion that perhaps the simplest life unit may be an excessively minute granule of chromatin with delicate fibrils extending from it, and that a cell is a combination of many of these minute elements. Other facts disclosed by the minute study of many animal cells, with very high magnifying powers and under special conditions, have pointed to a similar conclusion. As a result there has been advanced recently a theory that the cell is far from the simplest unit of life, and that it can be analyzed into a great number of minute elements called "chromidial units," each made of a granule of chromatin with fibers of linin radiating from it. According to this theory the whole cell is made of a network of linin fibers with granules at the nodes, each granule thus representing a life unit far simpler than a cell. This has been called the "protomitomic network." This protomitomic theory is as yet only a matter of speculation, and its chief interest to-day is in the fact that it suggests that the cell may be far from the simplest unit manifesting life. Whether this new suggestion be established or not, it seems certain that the manifestation of life requires the presence of three elements: (1) chromatin material, (2) delicate fibrils radiating from it, and (3) of a liquid material in which the other parts are embedded. As yet we know of nothing simpler than a combination of these three that is able to manifest all the properties of life.

LABORATORY WORK ON CELLS

A satisfactory study of cells requires familiarity with the microscope and considerable skill in microscopic methods. Little can be wisely undertaken by elementary students, beyond the examination of prepared specimens, properly stained, which should be furnished by the instructor. Drawings should be made by the student in all cases. The cellular structure of animal tissues may be studied in the following preparations: —

Blood.—A small drop of frog's blood in a little normal solution (.9%

NaCL) examined with a 1/6 inch objective, will show blood cells, the red cells having nucleii.

Cartilage.—Mounted sections of cartilage will show nearly rounded cells, embedded in a very thick mass of cell wall, the thickened cell wall forming the intercellular substance, or basis of the cartilage.

Bone.—Mounted sections will show cells lying in irregular spaces, within a hard secreted mass of intercellular substance in which mineral salts have been deposited.

The cellular structure of plants may be studied by the following preparations:—

Cork or *wood* sections show plant tissue made of numerous cells of varying shape. In these sections the cell walls only appear.

A section of a growing root tip. Longitudinal sections of *Podophyllum*, which are particularly good, should be furnished. These sections, if properly stained, will show the cell contents as well as the cell walls. The protoplasm and nucleus may be seen and drawn. In particularly good specimens, stained with iron hæmatoxylin, the chromatin in the nucleus may be seen with an oil immersion, 1/12 inch objective.

For the study of protoplasm *Spirogyra* is a favorable object. The student, after studying the normal specimen, should treat it with a little glycerine, which will cause the protoplasm to shrink away from the cell wall so that it can be seen.

The movement of the protoplasm within the cell is best seen in the long internodal cells of *Chara* or *Nitella*. It may also be seen in the stamen hairs of *Tradescantia*.

Ciliary motion may be studied best by cutting off a bit of the edge of the gill of a fresh-water clam, and examining with a high-power objective. It may also be shown by scraping the roof of a frog's mouth with a scalpel and mounting the scrapings in a little normal fluid.

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CHAPTER III

UNICELLULAR ORGANISMS

In order to become familiar with the general properties of living things, we will study the structure and functions of some of the simplest organisms. Those that are studied in this chapter are all microscopic, and belong to the group of unicellular organisms sometimes called **animalculæ.**

ANIMALS

The first organisms to be studied are undoubtedly to be regarded as animals.

AMŒBA

Size and Shape.—The *Amœba* (Gr. *amoibos* = changing) is a microscopic animal found both in fresh and salt water. The most common species averages about 1/100 of an inch in diameter, but the size varies in different species. With perseverance they may be discovered in nearly all bodies of water where there is mud and slime. One of the best methods of procuring them for study is to collect water plants (*Ceratophyllum*) or even pond-lily leaves, and to place them in dishes of water until they decay. After a couple of weeks or so a brown scum appears and an examination of this scum usually shows *Amœbæ* in abundance.

Under the microscope the *Amœba* is seen to be a single cell without definite form, the same animal undergoing constant changes in outline. Lobes are thrust out first in one direction and then in another (Fig. 19), and as soon as one lobe is protruded the contents of the body begin to flow into it and may continue to flow until the whole body substance has passed into the lobe, other lobes being formed in the meantime. By a continual protrusion of such lobes and the flowing of the body into them, the *Amœba* has a slow motion. These lobes are thus used as organs of locomotion and are called **pseudopodia** (Gr. *pseudos* = false + *pous* = foot).

There has been considerable speculation as to the forces which produce pseudopodia, and various attempts have been made to explain them by purely physical forces. It has been suggested that they are due to the adhesion of the sticky substance of which the animal is made, to the object upon which it rests.

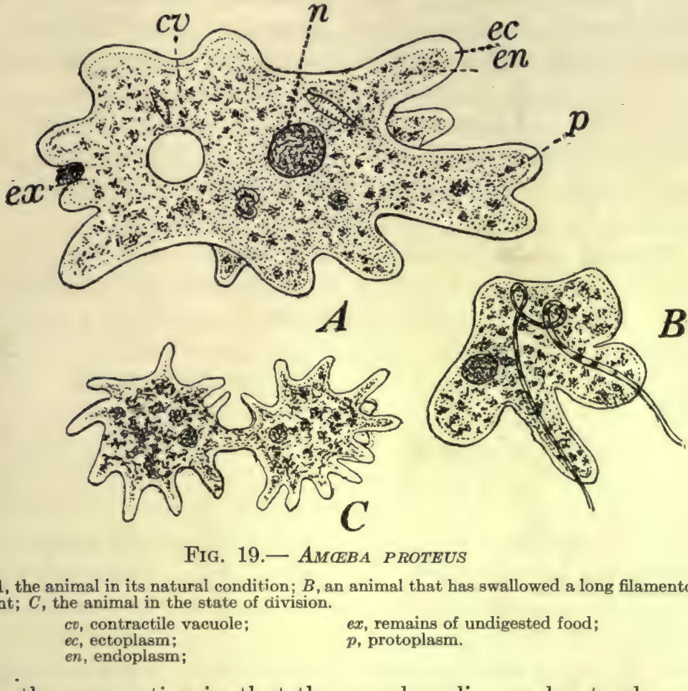

FIG. 19.— *AMŒBA PROTEUS*

A, the animal in its natural condition; *B*, an animal that has swallowed a long filamentous plant; *C*, the animal in the state of division.

cv, contractile vacuole;
ec, ectoplasm;
en, endoplasm;
ex, remains of undigested food;
p, protoplasm.

Another suggestion is, that the pseudopodia are due to changes in surface tension produced by the currents in the body as they flow to and fro. Still another theory seeks to explain the formation of pseudopodia by *stereotropism* (Gr. *stereos* = a solid + *tropé* = a turning), the attraction of a solid body for living tissue, which is supposed to cause the body of the animal to flow from one point to another of the surface upon which it rests. There is also the theory of chemical attraction.

However, the production of these pseudopodia cannot be satisfactorily explained by any of these means; enough careful study of the *Amœba* in motion has been made to show that the pseudopodia may be thrust out in any direction, either horizontally or vertically; and when thrust out vertically they may be bent forward until they come in contact with the surface on which the animal rests and then become attached. Their motion has to be explained by an active power of the living substance. This power on the part of the living substance has been called **contractility,** and it cannot be explained as due to any physical force like surface tension, adhesion, or chemical attraction, but is due rather to active contraction which must be regarded as a general function of the protoplasm of a living cell.

Structure.—The body of *Amœba* is made up of a transparent mass of protoplasm, in which there may be distinguished an outer clearer layer, called **ectoplasm** (Gr. *ectos* = outside + *plasma*), and an inner, more granular mass called **endoplasm** (Gr. *endon* = within + *plasma*). No very definite line can be drawn between them, the difference being due chiefly to the presence of granules in the interior and their absence from the outer layer. These granules are in motion, slowly circulating within the animal, and thus showing the existence of currents in the protoplasm. When the pseudopodia are protruded, the first change is the protrusion of a lobe of the ectoplasm; after which the granules can be seen flowing into the lobe until finally the whole of the endoplasm may flow into the extruded lobe. Many of these granules represent food in various stages of digestion, some of them being digested food and others undigested refuse. Among them may be found drops of clear liquid with a bit of digested food in their center.

Besides these granules, two more definite bodies are always found. One (Fig. 19 *n*), the **nucleus,** is a small rounded body near the center of the animal, but not fixed in position, since it moves with the protoplasmic current. This is one of the structural parts of the animal, not, like most of the granules, merely

extraneous material, and is always present in the living animal. The other body commonly found is the **contractile vacuole** (Lat. *vacuus* = empty) (Fig. 19 *cv*). This is a clear, pulsating drop, at one moment appearing as a good-sized sphere, and the next contracting and disappearing, to reappear again. It is thought that when it contracts, its contents, which are liquid, are forced out of the *Amœba's* body through minute openings that appear in its sides. These pulsations, which are fairly regular, plainly indicate the performance of some important function.

Assimilation and Growth.—When the *Amœba* comes in contact with a small plant or other bit of food, the pseudopodia flow around and over it so that the food is taken bodily inside the animal. The food may be taken in at any point on the surface of the *Amœba's* body, though more frequently it is engulfed by the anterior pseudopodia. As shown in Fig. 19 *B*, particles of food longer than the whole animal may be ingested. After a time the bit of food thus ingested begins to show signs of disintegration. It loses its sharp outline and becomes slowly softened and dissolved. This change is produced by the action of certain fluids which the animal secretes, and is a process of digestion. The nutritious portions become in time absorbed by the protoplasm and converted into new *Amœba* substance; the last process being assimilation. The refuse finds its way eventually to the surface of the animal, a temporary opening appears and the *Amœba* crawls away, leaving the refuse behind it; Fig. 19 *ex*. Any part of the body may thus serve for the ingestion of food or the ejection of refuse, although the food is commonly taken in at the anterior end, and the refuse ejected from the posterior end.

Respiration.—*Amœba* is not only carrying on a process of assimilation, by which new substances are built up, but is also at the same time carrying on a process of disintegration, by which the complex substances are broken down. This latter is based upon **oxidation** or union with oxygen. As the result of oxidation there is always formed carbon dioxid gas (CO_2) as a

waste product, which must be eliminated. The *Amœba* is, therefore, obliged to absorb oxygen gas from some source and to eliminate carbon dioxid gas. This process of absorbing and eliminating gases is known as **respiration.** In the *Amœba* there appear to be no special respiratory organs, although possibly the contractile vacuole performs this function. But the body of the animal is so small that special respiratory organs are unnecessary, since gas is readily absorbed directly through the surface of the body from the water in which the animal lives, and carbon dioxid is as readily eliminated into the water. A respiratory function is thus developed, but no distinct respiratory organs. The elimination of carbon dioxid gas, since it is the getting rid of a waste product of metabolism, is not only part of the function of respiration, but belongs also to the function of *excretion.*

Excretion.—As the result of this disintegration there arise in the *Amœba* disintegration products which are waste materials and must be eliminated from the body. These products are primarily three: *carbon dioxid gas, water,* and a product containing nitrogen, and related to *urea* which is excreted by the kidneys of higher animals. The function of getting rid of these waste products is called **excretion.** In *Amœba* the gas and the water are excreted directly into the surrounding water, either through the general surface of the body or by the contractile vacuole. The urea is probably eliminated by the contractile vacuole.

It should be clearly recognized that the elimination of the undigested portions of the food, mentioned on page 55, is not excretion. These undigested parts of the food, though sometimes called "excreta," have never become part of the *Amœba's* body and are simply foreign bodies that have been rejected as useless. True excretion, on the other hand, always refers to the elimination of the products of dissimilation.

Relation to Water.—Protoplasm requires water for its activities. Ordinary active living matter contains 60% to 80% of

water, and some forms of protoplasm much more, certain organisms containing over 95%. When dormant, protoplasm may remain alive with a far smaller percentage, dried seeds containing as little as 8%. Some animals also may be dried (*dessicated*) and still retain their vitality for a long time. This is true of many of the microscopic, unicellular animals and also of some of the higher types (*e. g., Hydatina;* see Fig. 116). In all such cases life activities are suspended but will be resumed when the animal imbibes water.

Irritability.—The *Amœba* has no sense organs nor does it have any nervous system. It is difficult or impossible to determine positively whether it has any conscious sensations, but it certainly has the power of reacting when stimulated, thus showing that it possesses *irritability.*

Reaction to contact (*Thigmotropism*) (Gr. *thigma* = touch + *tropé* = a turning).—If the moving *Amœba* is touched by a solid object, the part touched draws away from the object, new pseudopodia being thrust out in another direction. If, however, the object be a particle of food, the animal is differently affected and the pseudopodia flow around it so as to engulf it.

Reaction to chemicals (*Chemotropism*) (Gr. *chemesa* = chemistry + *tropé*).— If certain chemicals are brought in contact with the *Amœba,* it moves off in some other direction. Sugar, lactic acid, sodium chloride, and many other substances have this effect.

Reaction to heat (*Thermotropism*) (Gr. *thermos* = heat + *tropé*).—The activities of the *Amœba* are directly dependent upon temperature. At a temperature of freezing, no activities are manifest. If the temperature is raised the activities begin and become more active with the increase in temperature up to a certain point, about 85° F. If warmed still more, they become less active, and when heated to about 90° F. the activities cease entirely. At about 105° F. the protoplasm is coagulated and the animal killed. If a warm or hot object is brought near an active *Amœba* the animal moves away from it.

Reaction to light (*Phototropism*) (Gr. *photos* = light + *tropé*).—If a strong light is directed upon an *Amœba* from one side, it will move away from the light. A strong, white light may cause the animal to stop moving.

Reaction to electricity (*Electropism*) (Eng. *electro* + Gr. *tropé*).—If an electric current is passed through an *Amœba*, it contracts on the side of the positive pole of the current and moves toward the negative pole.

In all these cases the *Amœba* reacts to a stimulus. But there are other things which are irritable and react to a stimulus in a purely mechanical fashion. Gunpowder is also irritable, since it will react to heat with an explosion. A locomotive is irritable, since it will react to a touch upon its throttle valve. The *Amœba* certainly reacts in a more complex and more varied manner, but the question inevitably arises whether the action may not be simply that of a bit of machinery responding to its appropriate stimulus. There is no definite answer to this question that can yet be given.

Reproduction.—As the *Amœba* by assimilation converts its food into new protoplasm, it inevitably increases in size. If this went on without interruption there would be no limit to the size of the animal. But after growing for a time, a constriction appears in the middle of the body which deepens until it finally divides the animal into two parts; Fig. 19 *C*. Each of the resulting parts is like the other and each like the original except in size. It is the nucleus that seems to take the lead in this process of division, which is one of great complexity. This will be described in the next chapter, for it goes through the complicated series of changes known as *karyokinesis* (Gr. *karyon* = nucleus + *kinesis* = movement) described on page 85. As a result of this division there arise two animals, evidently alike, each of which now moves away and lives an independent life. This method of reproduction, by which the animal divides into two practically equal parts, is called **fission.**

A second method of reproduction sometimes occurs in

Amœba. This is very unusual, however, and has been seen by only one observer (Sheel). In this method the animal draws in its pseudopodia, assumes a spherical form and secretes around itself a thin shell called a **cyst**. Inside this cyst the nucleus divides into many parts, some five or six hundred nuclei thus finally arising by division. After this the rest of the substance divides so that each nucleus finally becomes surrounded by a little protoplasm, the contents of the cyst coming thus to consist of some hundreds of little bodies, each with its nucleus. Eventually the cyst bursts and the little cells escape, each being now a minute *Amœba*, which has only to grow, to be like the original. This method of reproduction is also evidently a division. It is a type of division called **spore formation.** The whole process takes two and a half to three months, and the conditions which bring it about are unknown.

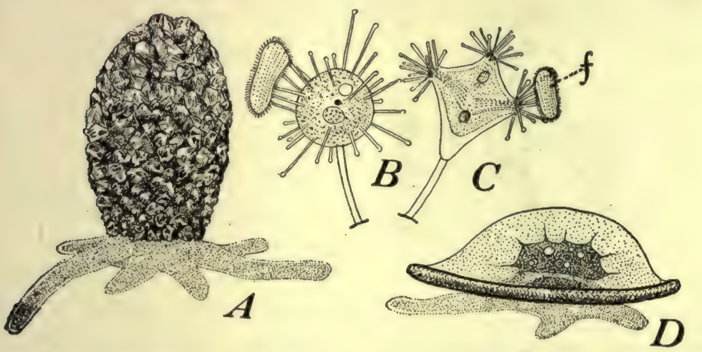

FIG. 20.—SINGLE-CELLED ANIMALS RELATED TO *AMŒBA*

A, *Difflugia*, an *Amœba*-like animal with a shell made of pebbles; *B* and *C*, *Podophrya* and *Acineta*, animals with stiff protruding tentacles of protoplasm; *f*, food; *D*, *Arcella*, an *Amœba*-like animal with a secreted shell.

PARAMECIUM

Paramecium can usually be found in the same localities as *Amœba* and can easily be obtained by allowing lily pads to decay in a dish of water. A quantity of living organisms soon

appears in the scum that forms on the surface, and among them may be seen some minute white specks, just visible to the naked eye, each one of which is a *Paramecium;* Fig. 21.

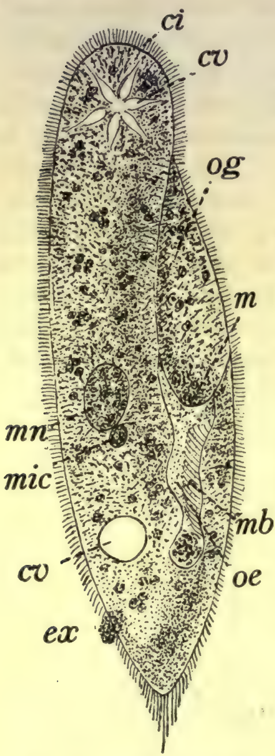

FIG. 21.—*PARAMECIUM AURELIA*

ci, cilia;
cv, contractile vacuole;
ex, excreta;
m, mouth;
mic, micronucleus;
mn, macronucleus;
mb, membranella;
oe, œsophagus;
og, oral groove.

Like the *Amœba*, it is a single cell, and like the *Amœba* also, it is made up of protoplasm consisting of an outer, somewhat clear **ectoplasm** and an inner, more granular **endoplasm.** The *Paramecium* has a body which, although flexible, is somewhat rigid and elastic, and, unlike the *Amœba,* always tends to preserve a definite form. It is elongated, somewhat blunter at one end than the other, and in its motion carries the blunt end forward. The protoplasm has no power of protruding pseudopodia, and the animal therefore does not change its shape like the *Amœba.* Upon one side, posterior to the middle of the body, there is a groove extending obliquely backward. This is the **oral groove** (*og*), at the bottom of which there is an opening leading to a short tube which extends through the ectoplasm into the endoplasm. The opening is the **mouth,** and the tube is known as the **œsophagus** or **gullet;** *oe.*

Locomotion.—The whole of the outer surface of the animal is covered with numerous, fine, threadlike projections of protoplasm, protruding from the ectoplasm into the water. These are called **cilia** and are capable of rapid motion back

and forth. Ordinarily in life, they are directed somewhat backwards, and as a result of this position, when they beat back and forth they cause the propulsion of the animal forward through the water with a uniform motion. When the cilia are directed forward, their beating back and forth will cause the animal to move backward. At the same time with their back-and-forth motion they beat slightly to one side, causing the animal to rotate slowly on its long axis as it moves either forward or backward. Exactly how these cilia are able to move is not known, but a power of automatic *vibration* is always characteristic of these organs. Lining the tube called the œsophagus, leading from the mouth, there are special cilia, longer than the rest and united to form a vibrating membrane known as **membranella;** Fig. 21 *mb*. The function of this mass of fused cilia is to guide the food from the mouth down through the œsophagus into the body cavity. The direction in which the cilia point, and consequently the direction of the motion they produce, are affected by a variety of external conditions, for the *Paramecium*, like the *Amœba*, is irritable and its motions are regulated by the surrounding conditions.

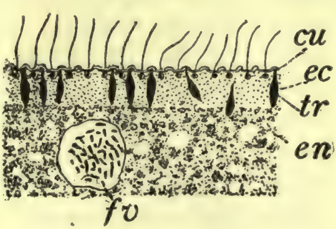

Fig. 22.—A bit of the outer edge of the *Paramecium* (highly magnified)

(Modified from Maier.)

cu, cuticle; *ec*, ectoplasm; *en*, endoplasm; *fv*, food vacuole; *tr*, trichocyst.

Structure.—The ectoplasm of the *Paramecium* is somewhat clearer than the endoplasm, but it contains large numbers of minute threadlike organs known as **trichocysts** (Gr. *trix* = hair + *cystis* = bag); Fig. 22 *tr*. These may be discharged from the animal; and they appear to be organs of offense or defense, since they apparently contain a small quantity of poison by which the animal may kill or paralyze its prey or its enemies. On the very outside of the ectoplasm is an extremely thin mem-

brane known as the cuticle (*cu*), through which the cilia protrude. This is ordinarily invisible and can only be seen under special conditions. It is a protective covering which makes the body a little more resistant than it otherwise would be. The endoplasm fills the rest of the body and is very highly granular, containing large numbers of food masses in various stages of digestion. The nucleus is double, showing a large **macronucleus*** (Fig. 21 *mn*), and near it a small **micronucleus**†, *mic*. These two bodies lie close together near the mouth and hold fairly constantly their relative positions in the body of the animal. Two **contractile vacuoles** (*cv*) are found in the common species of *Paramecium*, one at each end. These vacuoles connect with the different parts of the body by a number of minute radiating canals, six or ten in number, which extend in all directions. Certain liquids are, apparently, poured into these canals from the living protoplasm and through them flow into the vacuoles, which increase in size until they reach a certain magnitude and then suddenly contract and discharge their contents to the exterior, probably through minute openings. The contraction of the vacuoles is fairly regular, varying in rapidity with the temperature; the two vacuoles do not contract simultaneously, but alternate with each other. These organs, as in the case of the *Amœba*, are probably associated with the function of respiration and excretion.

Assimilation and Growth.—The food of the *Paramecium* consists chiefly of minute bacteria. These are driven into the mouth by the action of the cilia, and by the membranella in the œsophagus, and then guided down the œsophagus to its inner end. Here the bacteria collect in a little drop of water. The œsophagus then contracts and pinches off this little drop containing the bacteria, and thus forms what is called a food vacuole, which enters into the general mass of the endoplasm and follows the movement of the protoplasm around the body. The digestive juices are secreted and gradually digest the bac-

* Gr. *macros* = large. † Gr. *micros* = small.

teria, the nutritious portions of which are absorbed by the body and assimilated into new *Paramecium* substance. The undigested refuse portion is eventually discharged at the posterior end of the body on one side. There is no permanent opening here, but whenever material is to be rejected a temporary opening appears, at the point shown at Fig. 21 *ex*, and the refuse material is discharged into the water. The process by which food is used, including the absorption of oxygen and the excretion of waste products, as well as the oxidation of the food itself, is essentially identical with that in the *Amœba.* As the result of the process, the food material is eventually assimilated into new *Paramecium* substance, and the animal grows, increasing in size until it is ready for reproduction.

Irritability.—*Paramecium* is totally lacking in sensory organs or in a nervous system, but like the *Amœba* it reacts to a variety of stimuli. If an injurious stimulus is applied to one side of it, the animal will reverse its cilia and move away from the irritating stimulus. It may move backward or it may turn its forward end in any direction and move off to one side. It is attracted by certain chemical stimuli and repelled by others. It is affected by heat in the same way as the *Amœba.* It is slightly affected by an electric current, but is not affected by ordinary light, although the so-called ultra-violet rays have an influence upon it. These various reactions give to *Paramecia* an appearance of conscious sensation, and it appears as if they had the power of volition to enable them to avoid irritating or unpleasant conditions. But the facts do not necessarily prove this, for it is possible that these reactions are only mechanical responses to stimuli, such as might be found in other machinery. The responses, however, are so complicated, and so resemble those of truly conscious animals, that it leads one to suspect that they are actually conscious functions.

Reproduction.—The ordinary method of reproduction of the *Paramecium* is by division (*fission*) similar to that of *Amœba,* although it is more complicated, since the animal is more com-

plex in structure. The first step in the process is the elongation and division of the micronucleus into two parts, one of which comes to lie at each end of the animal; Fig. 23. This is followed by a similar elongation and division of the macronucleus. The œsophagus produces a little bud which develops into a new œsophagus, and then this and the old one move apart, so that the latter advances to the front part of the body, and the former lies in the posterior part. A new membranella develops in the œsophagus. Two new contractile vacuoles make their appearance, one just in front of, and one just behind, the middle line of the body. Meantime a constriction has been making its appearance, which gradually deepens, cutting the animal into two parts by a cross division. The two halves thus produced separate from each other and swim away to live an independent life. It should be noted that in this reproduction each of the important parts of the animal divides, so that each of the two new individuals has a part of each organ which the original *Paramecium* possessed. This multiplication by division may go on almost indefinitely if the animal is properly fed and placed under favorable conditions. Ordinarily it will occur about once in twenty-four hours, although the frequency may vary, becoming greater or less with varying conditions of food and temperature. A continuous reproduction of this kind has been followed for over 2500 successive divisions. Whether it can go on indefinitely if the conditions were favorable is not known. It is known, however, that under ordinary conditions this power of reproduction gradually becomes less and less, and finally tends to disappear altogether. It is believed that in nature

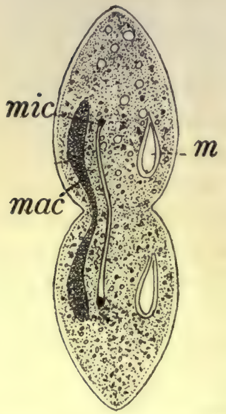

FIG. 23. — *PARAMECIUM* IN PROCESS OF DIVISION

m, mouth; *mac*, macronucleus; *mic*, micronucleus.

this disappearance of the power of multiplication and the natural disappearance of the race is prevented by the occurrence of another process known as **conjugation** (Lat. *con* = together + *jugare* = to join).

Conjugation.—Two individual *Paramecia* come together and place themselves side by side, adhering to each other as shown in Fig. 24 *a*. They do not actually fuse together, but remain attached. The micronucleus in each undergoes a series of changes which results in its dividing into several parts, three of which degenerate and disappear; *c*. Soon the fourth divides again into two, one of which is slightly larger than the other; *d*. The smaller part resulting from this last division passes over into the other of the two conjugating individuals, the two animals thus exchanging nuclear matter with each other, as shown by the arrows in *d*. This small piece of the micronucleus, thus exchanged by each individual, unites in each case with the larger piece of the nucleus remaining in the other individual, and the two combine to form a new nucleus, a **fusion nucleus,** shown at *f*. The animals now separate, each of them carrying off in itself a bit of the micronucleus from the other individual. The old macronucleus next disintegrates and disappears (*f*), and the fusion nucleus divides into eight parts (*g*), three of which soon degenerate. One of the five that are left remains as a micronucleus, while the other four become macronuclei, at *h*. At this stage of the process each *Paramecium* has one micronucleus and four macronuclei. Next the micronucleus divides into two, and the entire animal divides at once into two separate parts, giving one-half of the micronucleus to each part. This gives two individuals, each with a micronucleus and two macronuclei; *i* to *k*. The process is again repeated, the micronucleus and the whole animal, except the macronuclei, dividing; the result is two more individuals, each containing one micronucleus and one macronucleus; *l* to *m*. This brings the animal back to its original condition, and now the ordinary process of fission begins and may go on again indefinitely, both micro- and macro-nuclei

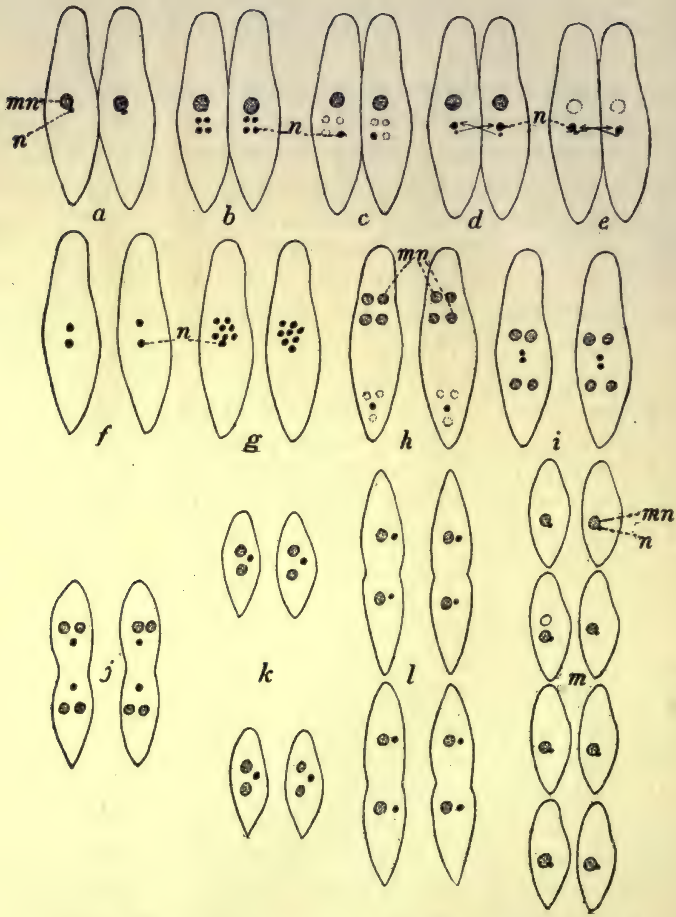

FIG. 24.—CONJUGATION OF *PARAMECIUM*

For the description of the various stages, see text; *m*, in all cases represents the macronucleus; *n*, the micronucleus. (Modified from Maupas.)

dividing with each subsequent cell division. Apparently the purpose of this conjugation is an interchange of the material present in the micronucleus; for it will be seen that after conjugation each of the resulting animals contains nuclear material derived from the micronucleus of the other individual as well as from its own.

The Life Cycle of Paramecium.—We usually think of the life history of higher animals as marked off in definite **life cycles.** For example, from the egg of the hen develops the chick, which grows into an adult hen and produces another egg and thus starts the process over again. Such a life cycle we speak of as comprising a single **generation,** and by the term **individual** we refer to all the stages of the life of the organism between one point in the cycle and the next similar point. When we attempt to think of the *Paramecium* in a similar way, we find the case so modified that the terms are somewhat difficult to apply. But still in the *Paramecium* we can recognize a life cycle somewhat similar to that of other organisms. We shall learn in a later chapter that the life of an animal like a hen begins with a single cell, which, dividing by a process similar to that we have just studied in the *Paramecium,* gives rise to a large number of cells; see Fig. 15. These, however, remain attached to form the individual which we speak of as the chick, which grows into the hen, and which is thus composed of large numbers of cells. This individual continues a separate existence and eventually a single cell is separated from it to form another egg and to start the process over again, in a new individual.

Now if we compare these facts with those just seen in the *Paramecium,* we shall find that the life cycle of the *Paramecium* is as follows: Starting in the cycle at the point where two animals separate after conjugation, there begins a series of cell divisions which rapidly increases the number of cells. The cells at once separate from each other, become perfectly independent, swimming apart as quite isolated animals. In this respect the development of the *Paramecium* differs very markedly from

that of the higher animals where the cells remain attached. But the process of division is the same and may continue for a long time. Eventually, however, as we have already seen, this power of division by the simple process of fission becomes exhausted, and the multiplication tends to die out. We can perhaps compare this with the old age of a larger animal, for in old age we find division becoming less and less vigorous, until it finally ceases altogether and the whole generation of cells dies. Among the larger animals, to prevent the extermination of the race, a single cell, an egg, is set aside to start the process over again, thus beginning the new cycle. In the case of the *Paramecium*, after the ordinary reproduction has gone on for a long time it becomes impaired in vigor and seems to be started over again by this process of conjugation. The process of conjugation, therefore, corresponds to reproduction by an egg in one of the larger animals or plants. Hence one life cycle of the *Paramecium* lasts from one period of conjugation, through all the numerous successive divisions by ordinary fission, until again the conjugation occurs to start a new cycle. One generation, then, consists of all the members that arise between one conjugation and the next; and inasmuch as these animals may multiply almost indefinitely by ordinary division, it is evident that one generation of *Paramecia* may consist of thousands of organisms scattered over a wide territory. It is evident, therefore, that the term individual in the case of the *Paramecium* cannot have the same significance that it has with the higher animals, since the individual of one of the higher animals would correspond to a combination of all of the different *Paramecia* that arise from the division of any single cell that comes from a process of conjugation, until again it enters into a process of conjugation with another cell. Conjugation thus starts a new generation or a new individual.

We do not know how long a time may elapse between two successive conjugations in the case of a *Paramecium*, nor do we know the conditions which bring about the process. We are

even ignorant as to its exact purpose, although it apparently appears to be a process necessary to reinvigorate the race and prevent it from dying out under the ordinary conditions of environment. The process is evidently closely associated with sex reproduction in the higher animals and plants, which is to be taken up in a later chapter. We may even speak of the *youth* and *maturity* of a *Paramecium;* by the term youth meaning the period of rapid cell division that follows conjugation, and by maturity and old age, the period of slower cell division that appears later in the life cycle of the animal. Possibly we may say that the animal eventually dies of old age, by which we would mean that unless conjugation occurs the process of simple division is brought to an end by exhaustion. Whether old age, and therefore conjugation, are necessary in the life history of *Paramecium* is not yet settled. Experiments have seemed to show that under proper conditions fission may go on almost indefinitely, certainly up to 2500 cell divisions, without the necessity of conjugation, or without seeming to produce any impairment in the power of division. In the normal life of the individual it appears that conjugation is required, however, by some of the conditions of life. *Paramecium*, therefore, has a definite life cycle, although we do not know its possible length or the conditions which modify it.

PLASMODIUM MALARIÆ

As an example of a still more minute animal, we will study the malarial organism, *Plasmodium malariæ*, which lives in the human body. Human blood contains minute circular disks known as red blood corpuscles (see page 192), within which the malarial organisms may be found in persons who are suffering from *malaria*, or *chills and fever*. The organism first appears as an extremely minute body (Fig. 25 *a*), in shape somewhat like the *Amœba*, though much smaller. It increases in size as shown by the successive figures *a* to *e*. After reaching a size which nearly fills up the red blood corpuscles, it breaks up

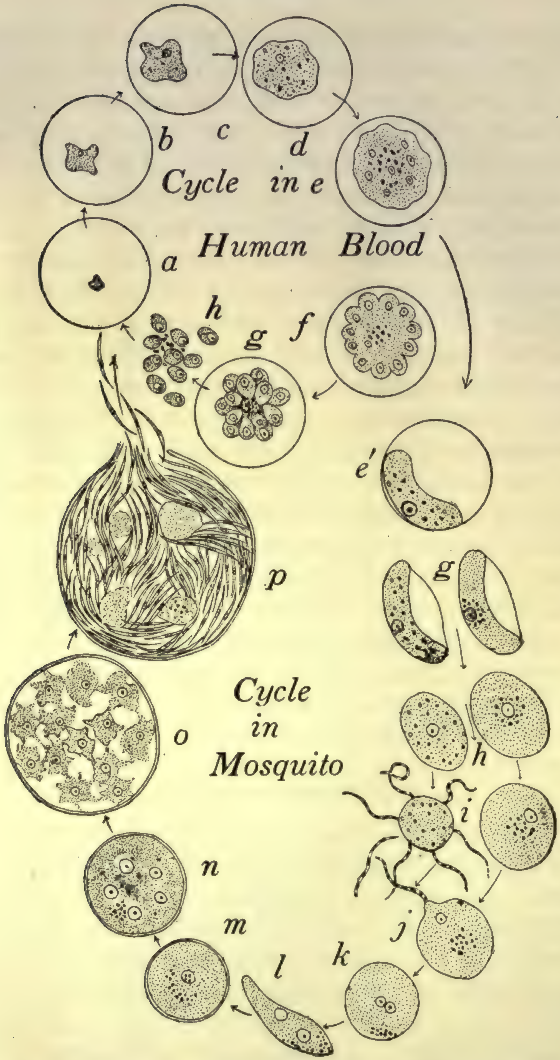

FIG. 25.—THE LIFE HISTORY OF THE MALARIAL ORGANISM

This is shown in two cycles, the upper one taking place in the human red blood corpuscles, and the lower one in the mosquito. For description of the individual stages, see text. (From various authors.)

into twelve to sixteen small **spores,** as is shown; *f* to *g*. The blood corpuscle now breaks to pieces and the spores are liberated into the liquid blood *h*. Each may then make its way into a new corpuscle and repeat again the history as already described.

Although this animal in its general structure and shape is much like the *Amœba*, its habits are totally different. While growing in the red blood corpuscles of the human body, it produces the disease which is known as malaria, chills and fever, or fever and ague. The period when the chills occur corresponds to the time when the blood corpuscles have broken up and the spores are liberated into the blood. The organism may continue to repeat the above history time after time in the blood of the same person, the spores after being liberated entering into new corpuscles, and again repeating their life cycle almost indefinitely and prolonging the disease. There are three different species of the malarial organisms, distinguished by the different length of time required for their life cycles. The most common form takes 48 hours, a second species takes 72 hours, and a third is irregular.

By the method of reproduction above described, this organism may multiply inside the blood of one person but is unable to pass to a second individual. Malaria is therefore not *communicable* as long as this process alone is repeated. But after a time, for some unknown reason, the organisms in the corpuscles assume two different forms shown in Figure 25 at *g* to *i*. One of them grows into a large rounded mass, while the other develops several long motile, thread-like bodies, which become detached. No further change occurs unless the patient is now bitten by a certain kind of mosquito (*Anopheles*). If the blood of a patient is swallowed by this mosquito, the malarial organisms undergo a new series of changes. The thread-like bodies become detached from the mass that produces them, and one of them unites with one of the larger rounded masses, *j* and *k*. This union is regarded as a sex union (see Chapter XII), the larger rounded mass being the female cell (or *egg*) and the thread-like body the male cell (or *sperm*) in the sexual union. After the thread-like

body penetrates the egg, the nucleus it contains unites with the nucleus of the egg, shown at *k* and *l*. After this union the combined mass grows rapidly in size, *l* to *o*, and eventually breaks up into an immense number of minute spores, *p*, greatly in excess of those found at the stage *g* in human blood. These minute spores lodge in the salivary glands of the mosquito, and are ejected into the blood of the person bitten by the mosquito. Thus a new human individual is inoculated with the spores, which find their way into the blood corpuscles of the new victim and produce the disease. It is not the most common mosquito (*Culex*) that is concerned in this history, but one that is ordinarily less abundant, a species called *Anopheles*. From these facts it follows that malaria will not occur in any locality unless this particular mosquito is present; and further, that only the mosquitoes which have previously bitten malarial patients will be able to carry the infection.

It will thus be seen that the malarial organism passes through two stages in its life cycle, reproducing itself in each by the production of spores, though the spores are of two different kinds; and that at one stage there is a union of cells of unequal size, which may probably be regarded as a true sex union. All stages of its life are passed within the bodies of other animals, and it is thus wholly *parasitic*. The three different species of the malarial organism have similar life cycles, though differing slightly in details.

The malarial organism passes through two stages, in its life cycle, each in different animals. Such a complicated history, in which there is more than one distinct stage, is known as a **metamorphosis** (Gr. *meta* = beyond + *morphé* = form). Many other animals have a metamorphosis, one of the best-known examples being that of the butterfly, which passes through the well-known states of *egg*, *caterpillar*, *cocoon*, and *butterfly*. Another example is the frog; see page 286. A metamorphosis is thus found both among higher animals and also among the lowest.

CHILOMONAS

This is an example of a still more minute organism found very abundantly the world over in water among decaying leaves. From Figure 26 it will be seen that its structure is extremely simple. It has a slightly elongated oval body, with a little depression at one end, at the bottom of which food is taken into the animal, the depression serving as a *mouth*. There are no internal indications of organs, except a small *nucleus*. At one end are two filaments called **flagella** (Lat. *flagellum* = a whip), which have the power of lashing to and fro. By means of their lashing the *Chilomonas* is driven through the water. *Chilomonas* multiples by simply dividing into two, essentially in the same manner as *Amœba*.

FIG. 26.—*CHILOMONAS* A very minute, flagellate, unicellular animal, found in stagnant water.

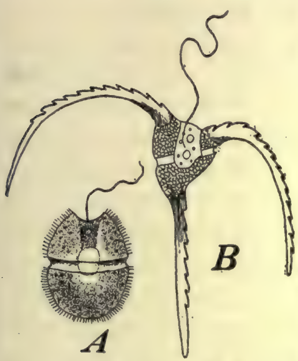

FIG. 27.—TWO SINGLE-CELLED ANIMALS, RELATED TO *CHILOMONAS*
A, *Gymnodinium*; *B*, *Ceratium*.

PANDORINA

Pandorina is an animal very similar in its general structure to *Chilomonas*, except that it is made up of a number of cells grouped together, instead of a single individual body; Fig. 28*A*. The method by which this group is formed is simple. The animal starts as a single cell, which divides, but after division the parts, instead of separating at once, remain attached, and there arises a group of sixteen cells attached together. They secrete a little mass of jelly around themselves and the flagella projecting through this jelly enable the whole spherical mass to be rotated as a unit. The individual members are somewhat independent of one another, but are attached so as to form one single unit. Such a group is called a **colony.**

Multiplication.—Reproduction of *Pandorina* is of two kinds: 1. Each of the cells of the colony divides into sixteen parts, which, however, remain attached together, making a cluster of sixteen groups of sixteen cells each. Then the whole colony breaks up, and each group of sixteen cells forms a new colony living independently of the others; Fig. 28 *B*. Thus, by simply dividing, the original colony produces sixteen others.

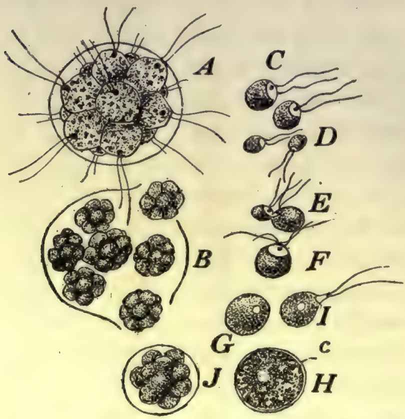

FIG. 28.— *PANDORINA*, A COMMON FRESH-WATER, COLONIAL, UNICELLULAR ANIMAL

A, the animal in its adult condition.
B, showing the method of reproduction by simple division, each cell dividing into sixteen parts and the whole colony breaking up into sixteen colonies.
C to *J* shows the successive stages of reproduction accompanied by conjugation; *C*, the larger of the uniting cells; *D*, the smaller ones; *E*, their conjugation; *H*, the dormant condition within the cyst. For description, see text.

2. By the second method of reproduction a conjugation occurs. The cells of a colony break into either sixteen or thirty-two parts, and then the whole mass breaks to pieces, each cell separating, not only from the colony but from its sister cells. Among the hundreds of cells thus formed some are smaller than others; Fig. 28 *C* and *D*. After swimming around for a while one of the smaller and one of the larger cells unite with each other; Fig. 28 *E* and *F*. The combined mass then secretes a red shell or **cyst** about itself and remains dormant for a time, showing no signs of motility, *H*. Later, however, it resumes its activity and may divide into two or three parts, which then escape from the cyst and swim around for a time as single cells, called **swarm spores,** *I*. Eventually each divides into sixteen cells which remain together, forming a new colony like the original, *J*

INTERMEDIATE ORGANISMS

The organisms thus far described are always classed as animals. We will now study two similar organisms, which stand midway between animals and plants. They are closely related, and yet one of them is not infrequently classed as a plant, while the other is almost always placed with the animals.

PERANEMA

Peranema is a microscopic organism found in stagnant fresh water; Fig. 29 *A*. It is elongated and tapers slightly in front. At the narrower end, which is carried forward in locomotion, there projects a long motile **flagellum,** by the motion of which the animal is moved through the water. At the base of this flagellum is an opening in the animal, constituting a **mouth,** leading into a short **œsophagal tube.** At the bottom of this tube is a peculiar little rod-shaped organ, which apparently serves as a sucking organ for seizing food. Near by is a clear **contractile vacuole.** The protoplasm of which the body is made is extremely flexible, and the animal, instead of retaining its shape, shows a variety of irregular wavelike contractions passing from end to end. A **nucleus** is present, and the animal moves either by the motion of its flagella or by creeping somewhat after the fashion of the *Amœba.* As it possesses a mouth and an œsophagal tube, it lives on solid

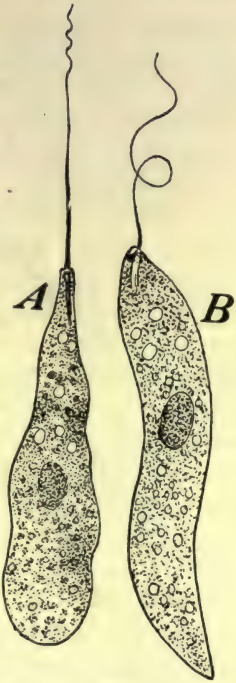

FIG. 29. — TWO SINGLE-CELLED ORGANISMS RESEMBLING BOTH ANIMALS AND PLANTS

A, Peranema; B, Euglena. *Peranema* is a colorless animal, while *Euglena* is bright green; in other respects they are much alike.

food and thus resembles *Paramecium* and the other animals already described.

EUGLENA

Euglena (Fig. 29 *B*) greatly resembles *Peranema* in shape and structure. Like the *Peranema*, it has an elongated body, tapering, however, at both ends. One end carries a long, motile flagellum by means of which the animal moves through the water. It is made up of flexible protoplasm and goes through a series of contorted motions similar to those seen in *Peranema*. One or more contractile vacuoles are found near the base of the flagellum. The animal moves about either by its flagellum or by the creeping motion noticed in *Peranema*. It has also a reddish "eye spot" near the front end.

Evidently, these two organisms are very closely related. In two respects, however, there is a striking difference, which has led to the classification of the *Euglena* by some biologists among the plants instead of among the animals. The *Euglena* probably possesses no true mouth and does not take in solid food, though this is disputed. Moreover, this animal is *green*, and since green coloring matter is one of the distinctive characters of plants, its presence in *Euglena* has led to much controversy regarding the classification of this organism. *Peranema* with its mouth and the animal habits should evidently be classed with the animals, whereas *Euglena*, with its green color, would naturally be classed with the plants; and yet their similarity would lead to classing them together. A further consideration of this subject will be given in a later chapter.

PLANTS

Although there is a difference of opinion in regard to the classification of *Euglena* and *Peranema*, there is none in regard to the organisms which are now to be described. The following organisms are always recognized as plants, although some of them, for reasons that will be given later, have certain charac-

ters that have caused biologists, in the past, to group them with animals. Modern scientists, however, are unanimous in opinion, grouping the following organisms among the plants.

PLEUROCOCCUS

Pleurococcus appears like a green stain, growing in abundance upon damp tree trunks, fence posts, or even damp rocks. Upon scraping off some of the material and examining it with a microscope it is found to consist of a great number of small green cells. These (Fig. 30) are spherical, and contain no visible internal organs except a **nucleus.** The cells are found massed together into irregular bunches, but are not really attached together. As they grow in size they divide by fission in two parts, each of which divides subsequently, the new individuals sometimes remaining attached, to form irregular masses which are easily shaken apart. No other method of reproduction is known. It is possible that this little plant is really a stage in the life of some higher plant whose development is not yet known, since it has been shown that some of the more complex plants have a stage in which they are simple green cells like *Pleurococcus*. Concerning this organism, however, nothing is known positively except that it occurs abundantly in damp places and, so far as known, has no other phase of its life than that already noticed.

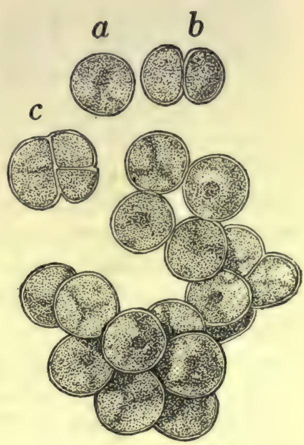

FIG. 30.—*PLEUROCOCCUS*

a, a single cell; *b*, one showing division by fission; *c*, a later stage of division. The plant in its growing condition is bright green.

SACCHAROMYCES—YEAST

The yeast is a plant slightly smaller than *Pleurococcus* but resembling it in its general shape, although it differs in some important respects. It is made up of single cells, usually slightly oval in shape, although sometimes they are elongated and occasionally spherical; see Fig. 31. These organisms are extremely minute in size, not being more than 1/4000 of an inch in diameter. They are so small that almost no internal structure can be seen, although each one of them possesses a nucleus and a small vacuole which is not contractile; Fig. 32. As each of these bodies possesses a nucleus, it is a cell, and thus we see that the yeast is made up of clusters of single cells.

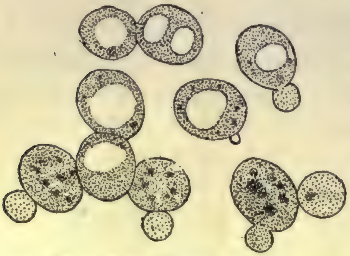

FIG. 31.—YEAST CELLS
Showing budding and formation of groups of cells.

Reproduction.—The method of reproduction of yeast is by the growth of buds on the side of the old cell. The bud appears first as a swelling, which grows until it is the size of the original cell, and may then break away and become an independent cell (Fig. 32), or several of them may remain attached together for some time, forming a group of more or less independent cells. This process is called **budding.**

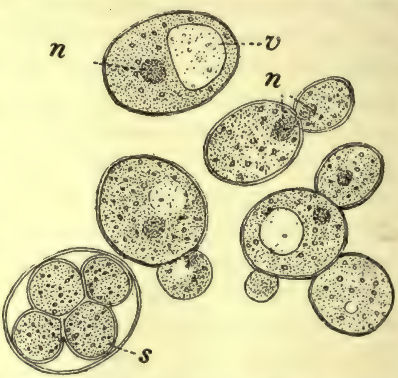

FIG. 32.—YEAST CELLS MORE HIGHLY MAGNIFIED AND WITH INTERNAL STRUCTURE SHOWN

n, the nucleus;
v, the vacuole;
s, shows spores in the spore sac or ascus.

The figures show that in budding the nucleus divides, one portion of it passing into the bud and the other remaining in the mother cell.

A second type of reproduction sometimes occurs in some species of yeast. Under conditions not yet clearly understood, the contents of a yeast cell breaks up into two, three, or four parts which become surrounded by thick walls; Fig. 32 *s*. These are called **spores,** or **ascospores,** because held in an **ascus** (Gr. *ascus* = sac) or sac, and eventually they are liberated by the breaking of the sac. Each spore is tnen capable of starting a new series of generations of ordinary yeast cells. The spores can resist drying and therefore serve to protect the yeast from adverse conditions.

A comparison of Figures 30 and 31 will show that yeast and *Pleurococcus* greatly resemble each other in structure; but there is one important difference between them, for *Pleurococcus* is green and yeast is colorless. This difference in color makes a very great difference in their life; see page 131. Whereas *Pleurococcus* may grow luxuriantly upon a fence post, and even bare rocks, feeding upon the gases of the air, yeast is unable to live and grow unless it is fed upon some organic matter, like sugar. While yeast cells may be found widely distributed in the air, in the soil, and in the water, they grow only where they find organic food to eat, and chiefly in solutions containing sugar, like fruit juices, etc. Elsewhere, in the soil or air, while they may be alive, they are dormant.

The chief function of yeast in nature is to convert sugars into carbon dioxid and alcohol. Sugar is produced in great quantities by various fruits and vegetables, and is eventually attacked by the numerous yeasts that are floating in the air. After the yeasts have acted upon it, the sugar disappears and in its place can be found a gas, *carbon dioxid* (CO_2), and a liquid, *alcohol* (C_2H_6O). This is called **fermentation,** and it is used extensively in the fermentative industries which produce alcoholic beverages, like *beers, wines, ales, brandies,* etc. The fermentation by yeasts is also made use of in the raising of bread. The yeast growing in the midst of bread dough produces bubbles of carbonic acid gas which cause the solid heavy dough to become light and

spongy. The bread made from such dough is full of holes, and is more palatable and digestible than bread cooked from dough that has not been rendered light and porous (*i.e.*, unleavened bread). In the case of bread raising and beer making, the yeast as a rule is intentionally planted in the material which is to be fermented. In the making of wines or the making of cider, yeast is not planted. In these cases, the grape juice or the apple juice is allowed to stand undisturbed, and the yeasts that are floating around in the air, known sometimes as "wild yeasts," have an opportunity of getting into the juices, where they grow and produce fermentation. Thus although no yeast has been added to these materials, the fermentation is brought about by yeast exactly as if the yeast had intentionally been added.

BACTERIA

The simplest of all known living organisms are the *Bacteria.* These consist of the extremely minute organisms shown in Figure 33. Some of them are spherical, some are in the form of short rods or long threads, and some spiral. They are so minute that practically no

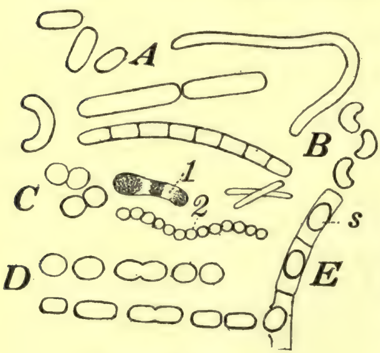

FIG. 33.—BACTERIA

A, rod-shaped form, *Bacillus* or *Bacterium;* 1, *Diphtheria bacillus; B*, spiral forms, *Spirillum; C*, spherical forms, *Coccus;* 2, *Streptococcus; D*, the method of multiplication by division; *E*, the formation of spores, *s*.

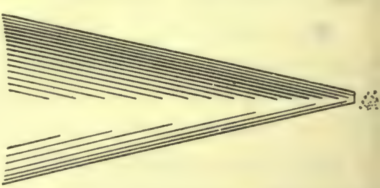

FIG. 34.—A DIAGRAM SHOWING THE RELATIVE SIZE OF THE POINT OF A FINE NEEDLE AND BACTERIA

The small dots at the tip of the needle represent bacteria.

internal structure can be seen. Some of them are not more than 1/50,000 of an inch in diameter; see Fig. 34. Some

bacteria (see Fig. 35) have minute **flagella**, which by lashing to and fro cause them to move. Beyond the points shown in the figures, there is very little to be said concerning the structure of bacteria.

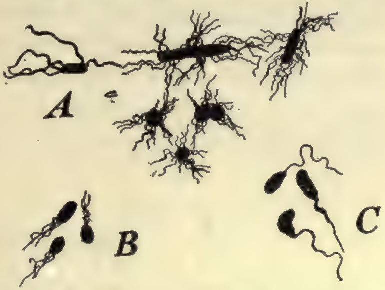

FIG. 35.—BACTERIA WITH FLAGELLA
A, flagella are distributed over the whole body, a condition called *peritrichic; B*, flagella grouped together in cluster at one end, called *lophotrichic; C*, a single flagellum, *monotrichic*.*

Reproduction.—Bacteria all multiply, by fission, each dividing into two parts, which again divide when they have grown to the size of the parent cell.

Spore Formation.—Some species of bacteria produce spores in the following manner: After growing for a time by division the contents of a single bacterium collect into a rounded mass which becomes surrounded by a hard resisting wall; see Fig. 33*E*. This is set free by the breaking of the bacterium that holds it and is then capable of starting a new series of generations. This clearly resembles the ascospore formation in yeast, except that there is no actual multiplication of individuals, one bacterium giving rise to one spore only. The spores have resisting walls and are able to stand drying and a fairly high degree of heat. Their function is thus that of protecting the race from destruction by drying and heat rather than that of multiplication, the latter function being performed by the process of simple division.

Bacteria are very widely distributed in nature. They are found in the air, in the soil, in all bodies of water, and, in fact, practically everywhere. They play an extremely important part in the life processes of nature through their relation to all forms of *putrefaction*, *decomposition*, and *decay*. The bacteria are important agents in maintaining the continued fertility of the soil, making it capable of producing crops year after year. A few species live as parasites within human bodies

$$\left.\begin{array}{l}\text{*Gr. } \textit{peri} = \text{around}\\ \text{Gr. } \textit{lophos} = \text{tuft}\\ \text{Gr. } \textit{monos} = \text{one}\end{array}\right\} + \textit{trix} = \text{hair.}$$

and those of animals. These are **pathogenic bacteria** or **disease germs.** They cause many of our most serious contagious diseases like *typhoid fever, tuberculosis, diphtheria, blood poisoning,* etc. Thus, although they are extremely minute, bacteria are agents of great importance in the world. It is hardly possible to imagine anything more simple in structure, but at the same time of greater importance, than bacteria.

LABORATORY WORK

The best method of obtaining material for laboratory work is to place in a number of glass jars or shallow dishes pond-lily leaves, leaves of other plants, algæ of various kinds, or any other decaying organic material from ponds and ditches. Fill the dishes with water and allow them to stand undisturbed from one to several weeks. Various kinds of microscopic organisms will appear in the different dishes, from which the desired organism can be chosen.

Amœba.—A brown scum will usually appear in a few days on the surface of the water covering the decaying organic material which is likely to contain *Amœbæ.* When this scum is scraped from the leaves and studied under a 1/6 inch objective it will usually disclose small specimens of *Amœba.* The animals should be studied alive and without any special treatment, since they are sufficiently transparent, and slow enough in their movements to show all the points in their anatomy, and nearly all the features mentioned in the text may be seen without difficulty.

Paramecium.— These may be found in abundance in the scum from the decaying pond weeds after they have been left for a week or more. Many white, moving bodies, just visible to the naked eye, will be found in a drop of this scum, which should be studied with a 1/6 inch objective. The chief difficulty in studying them is due to their constant motion; various methods of holding them quiet may be used. A bit of filter paper under the cover glass will sometimes hold the individuals quiet in its meshes, or they may be held quiet under a cover glass by supporting it on a small bit of paper, just thick enough to hold them without crushing them. The animals are to be studied alive, and a little patient examination of several specimens will usually show most of the points of structure mentioned in the text. To bring out the nucleus, a very weak aqueous solution of methyl green should be run under the cover glass. If the solution is not too strong it will stain the nucleii green, before affecting the rest of the organism. Animals

in the state of division may readily be found. Conjugation, however, is rare and cannot be studied by a class.

The other unicellular animals mentioned in Chapter II may be commonly found with *Amœba* and *Paramecium*. They cannot always be obtained, however, and the student will often be obliged to omit them. *Euglena* should not be omitted, however, if any appear in the dishes of decaying pond weeds.

Pleurococcus.—The best method of obtaining this for study is to find some fence post or log which is covered with a green growth. This material scraped from the wood will usually prove to be a mass of *Pleurococci.* No special method of study is needed except to place a small quantity in a drop of water and study with a 1/6 inch objective. The structure can be readily seen and cells may be found showing division by fission.

Yeast.—A cake of ordinary compressed yeast furnishes excellent material. A small quantity should be rubbed with a little water in a watch glass. A minute drop of this material diluted still further in water, and studied with a 1/6 inch, will show the structure of the yeast except the nucleus, which can only be made out by special methods. Many cells showing buds may be found in a fresh yeast cake. Such a yeast preparation usually contains grains of starch, which may be distinguished from the yeast by running a little iodine solution under the cover glass, which will turn the starch blue. The starch has nothing to do with the yeast, being added to the cake to give it body. A few drops of the yeast emulsion should be planted in several large test tubes containing a fermentable liquid. Pasteur's solution is best, but a little diluted molasses will serve. Pasteur's solution contains the following ingredients: —

Water	837.60	c. c.
Grape sugar	150	gms.
Ammonium tartrate	10	"
Potassium phosphate	2	"
Calcium phosphate	.2	"
Magnesium sulphate	.2	"
	1000	

If these tubes are placed in a warm place, 80° to 90° F., fermentation will soon begin, and after a few hours bubbles of CO_2 may be seen rising through the liquid. After 12 hours a little of the scum or the sediment will show the actively growing yeast. This growing yeast should be carefully compared with the fresh, dormant yeast in the yeast cake.

Bacteria.—Only a little work can be done without special methods which are complicated and difficult. Bacteria may be shown, however, as follows:

Spread a bit of any decaying matter (the decaying pond weeds will do very well, or a bit of tartar scraped from the teeth) in as thin a film as possible upon a slide, dry in air or fix by heat by passing it twice through a gas flame. When thoroughly dry flood the slide with a solution of fuchsin or methylene* blue and allow to stain for two to five minutes. Then wash the stain off in running water, and place a cover glass over the stained mass on the slide. The bacteria appear under a high power objective as minute stained dots, or short rods. They are much smaller than yeast cells, and are only just visible with a 1/6 inch objective. Higher powers are needed to study them.

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*Methylene blue solution is made as follows:—

Saturated alcoholic solution of methylene blue . . .	15 c. c.
Potassium hydrate (1:10,000)	50 c. c.

To make a 1:10,000 solution of KOH, add 1 c. c. of a 10% solution to 99 c. c. of water and then add 5 c. c. of this to 45 c. c. of water.

CHAPTER IV

CELL MULTIPLICATION AND THE CELLULAR STRUCTURE OF ORGANISMS

BEFORE undertaking the study of the multicellular organisms we must study in detail the process by which cells multiply. We have already seen that the *Amœba*, *Paramecium*, and other single-celled animals and plants have the power of dividing. Indeed all active, growing cells have the power of multiplying by division. Although division seems a very simple process, in reality it is unexpectedly complex. The internal changes in the cell during division have been made out only by long study. While they differ in many small details, all cells agree in certain broad general facts. The process known as **karyokinesis** or **mitosis** (Gr. *mitos* = thread) is alike in outline in most cells and is as follows: —

CELL DIVISION OR KARYOKINESIS *

The Resting Cell.— In Figure 36 *A* will be seen a cell in the condition of rest, before it has passed into the stage of division. It will be noticed that the centrosome is in the form of two minute granules, and that the chromatin inside of the nucleus is in the form of a diffused network. No other factors need concern us at the present time.

1. **Prophase.**—The first stage in the division involves both the nucleus and the centrosome. In the nucleus the chromatin assumes the form of a long thread sometimes known as the **spireme.** This condition, however, is only preliminary to the breaking up of the thread into a number of short pieces which are called **chromosomes** (Gr. *chroma* = color + *soma* = body); Fig. 36 *B*. The number of chromosomes which arise in the nucleus varies with different organisms but is constant for each species of organism and is always an even number. In the

*As here described karyokinesis applies chiefly to animal cells.

type represented in Figure 36, the number of chromosomes is invariably four.

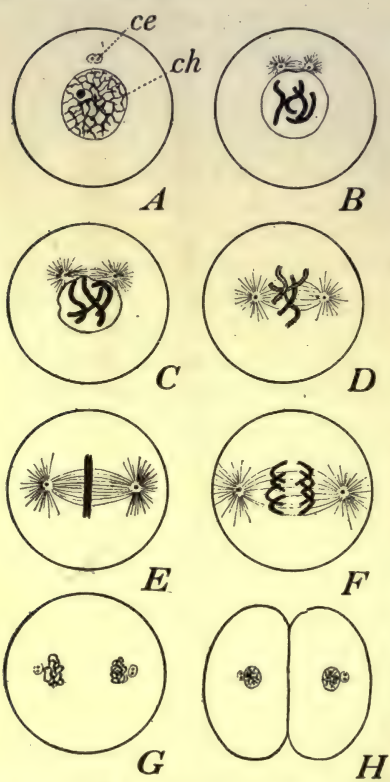

FIG. 36. — DIAGRAM SHOWING THE SUCCESSIVE STAGES IN THE PROCESS OF KARYOKINESIS

A, the resting cell before it enters into the process of cell division; *H*, the completed process after the cell has divided into two parts; *ce*, the centrosome; *ch*, the chromatin. For description of the different stages, see text.

The second part of the first stage consists of the separation of the two granules of the centrosome as shown at *B*. As these parts separate, they are seen to be connected by fibers forming what is called the **spindle.** The granules continue to move away from each other until they finally come to lie at opposite poles of the nucleus, forming the **amphiaster** (Gr. *amphi* = both + *aster* = star) as shown at *D*. They are still connected by the fibers of the spindle, which now pass into the nucleus itself; the nuclear membrane in the meantime has disappeared. At the end of this phase the chromosomes have assumed a position midway between the two granules, lying on the middle of the spindle, and at right angles to the line connecting them, at *E*. They thus form a sort of plate between the two poles of the spindle, known as the **equatorial plate.** The formation of the chromosomes and the separation of the centrosomes may take

place simultaneously, or one of them may precede the other; the relative order of these changes varies and is a matter of no especial importance.

2. **Metaphase.**—The second stage in cell division is a very important one and is really the key to the process. Each of the chromosomes splits lengthwise into two identical halves, which at first are parallel, as at *D*. This splitting of the chromosome into identical halves is for the purpose of dividing equally the chromatin material, so that the two cells which are to arise from the original cell may each contain one-half of the chromatin rods of the original cell. The fact that the chromosomes split lengthwise is of significance, for it is manifest that if the thread splits lengthwise, the two halves will be essentially identical, while if it should divide crosswise, the two halves would not be necessarily alike. In the equatorial plate, at *E*, these eight chromosomes become slightly flattened and are drawn more closely together.

3. **Anaphase.**—In the third stage, the two halves of each chromosome begin to move apart. As shown at *F*, four of the chromosomes move away from the equatorial plate toward each of the two centrosomes. There is little doubt that the minute fibers which connect the poles of this spindle are concerned in the separation of these chromatin threads, though exactly how they work is not known. Finally, the separate halves of the chromatin thread are brought close to the minute granules lying at the two ends of the spindle, at *G*.

4. **Telophase.**—The last stage in the division simply completes the process, for the essential feature of division has already occurred. The chromatin threads, which have come to lie near the pole of the spindle, now combine and form a network, at *G*, much like that present in the original nucleus, and a nuclear membrane forms around this mass of chromatin material at *H*. The minute granule within the center of the spindle pole is divided in two, either now or later; and thus a complete nucleus is produced with a centrosome beside it,

containing two granules, at *H;* this nucleus is an exact repetition of the one with which we started. Meantime a division plane forms, passing through the cell midway between these reconstructed nuclei, and the division of the cell into two parts is now completed. There are thus produced two cells, identical with each other and identical with the original cell, each with similar chromatin material, since each contains half of the original chromosomes. By this process, therefore, the chromatin of the nucleus is continuous from one cell generation to another.

It will be evident that the essential purpose of this cell division is the splitting of the chromatin material into identical halves. It would seem much simpler for the cell to divide immediately into two parts without this long process; but this might not make the two parts equivalent. In order that they may be equivalent, the cell adopts the complicated process of karyokinesis. In the case described, the two final cells are practically of equal size; but even in instances where the cells finally produced are of very unequal size (Fig. 121), the amount of chromatin in each is the same. Since, therefore, the essential purpose of this process of karyokinesis is the splitting of the chromatin, it is evident that this material must be of extreme significance in the life of the cell. When we combine this knowledge with the fact mentioned in Chapter II, that the cell can carry on its life processes only when it has nuclear material, it becomes manifest that the nucleus, instead of being a negligible part of the cell, is really the central feature of its life.

Nuclear Division without Cell Division.—As a rule, almost immediately after the nucleus completes its division, the body of the cell divides so that a cell does not contain more than a single nucleus for any length of time. Occasionally, however, the division of the cell body is delayed and the nucleus divides a second time, and perhaps several times, before the cell body divides, the result being one mass of protoplasm containing

several nuclei. In most instances the division of the cell is simply delayed and takes place later, so that finally the condition of a single nucleus in each cell is resumed. This occurs in the dividing egg of insects, for example. In some instances, however, the cell body does not divide at all, and the continued division of the nucleus produces a connected mass of protoplasm with many nuclei. This occurs, for example, in some molds shown in Figure 42 *E*, in which there is no sign of cell division, although there are many nuclei. Such a condition is called a **syncytium** (Gr. *syn* = together + *cytos* = cell) and is sometimes described as **acellular.** This multicellular state with incompleted cell division is rare, for in most instances the division is completed promptly.

Amitosis.—While division by karyokinesis is the common method of cell division among all organisms, there are some instances where cells divide without going through these stages. This is most likely to occur in the old age of the cell when its vitality begins to decline. In these cases, the nucleus divides directly; sometimes being simply pinched into two parts (Fig. 37), sometimes being compressed into a middle plate which divides into two halves and then separates, and sometimes forming two nuclear membranes inside of the original membrane which then ruptures and permits the escape of the new nuclei. In these cases, it frequently happens that, though the nucleus divides, the cell body does not divide, so that there results a cell with more than one nucleus. This process of division is called **amitosis** (Gr. *a* = without + Lat. *mitos* = thread), and it is thought to indicate a decline in the vigor of the cells.

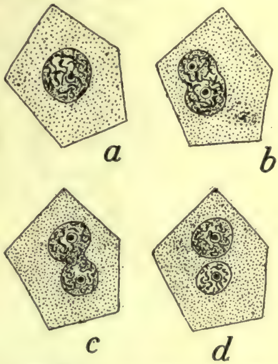

FIG. 37.—DIAGRAM SHOWING THE PROCESS OF NUCLEAR DIVISION BY AMITOSIS
(Modified from Wheeler.)

UNICELLULAR AND MULTICELLULAR ORGANISMS

All of the organisms thus far studied have been made up of single cells, each cell being independent and capable of carrying on all life processes within itself, although many of them are quite complex, having several organs and much variety; see Fig. 38. In contrast to these **unicellular organisms** we shall find organisms made up of large numbers of cells (**multicellular organisms**). All of the larger and higher animals and plants in the world are made up of great numbers of cells, each having the same general structure as the unicellular organisms we have already studied. These larger organisms begin their life as single cells and become multicellular by the division of their cells into many parts. There is no doubt that the multicellular organisms of the world must have been derived originally from the unicellular organisms.

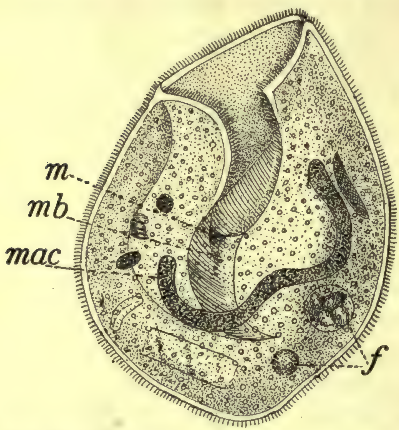

FIG. 38.—*BURSARIA*. ONE OF THE LARGEST AND MOST COMPLICATED OF THE SINGLE-CELLED ANIMALS

f, food; *mb*, membranella; *m*, mouth; *mac*, macronucleus.

Intermediate Types. — While the organisms described in the last chapter are called unicellular, there are some of them to which this term cannot be applied with strict accuracy. *Pandorina* (Fig. 28), for example, consists of a group of sixteen cells attached in a spherical, gelatinous mass. Each of these masses of sixteen cells has been derived from a single cell by division. It is a question whether this organism should be called unicellular or multicellular. It is certainly made up of more than one cell; but

on the other hand the cells are all alike, are all capable of carrying on the various functions of life, and may be more or less independent of each other.

Vorticella and Carchesium.—Other examples of types intermediate between unicellular and multicellular forms are shown in Figures 39 and 40. The *Vorticella*, shown at Figure 39 *A*,

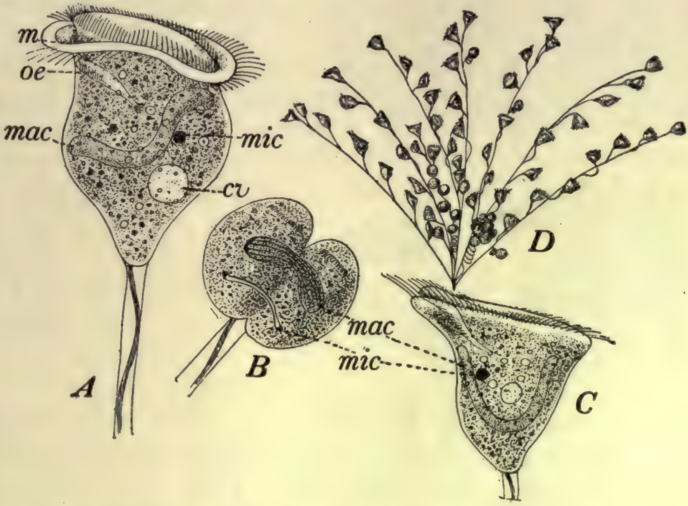

FIG. 39.—TWO SPECIES OF UNICELLULAR ORGANISMS

Showing the formation of colonies. *A*, a single-celled *Vorticella; B*, the process of division; *C*, a single cell of *Carchesium; D*, a colony of *Carchesium*, produced by the incomplete division. *Vorticella* always separates after division, but *Carchesium* remains attached as shown at *D*.

cv, contractile vacuole; *mac*, macronucleus;
oe, œsophagus; *mic*, micronucleus.
m, mouth;

is unquestionably a single-celled animal, bell-shaped and possessing cilia, a mouth, œsophagus, vacuole, and a macro- and micronucleus; the whole is attached to a stalk containing a muscle which enables it to contract. This single cell divides in a normal manner (*B*) and after division the parts separate

to become independent animals. In Figure *C* is shown another cell much like *Vorticella,* possessing the same shape and similar organs. In this animal, after the cells divide, they do not separate but remain attached to a common stalk, and subsequently divide again and again, the result being a group of similar cells connected by a branching stalk, *D*. This animal is named *Carchesium,* and such a cluster is called a **colony.** In this colony the members are independent, each carrying on for itself all of the functions of life and each contracting and expanding by itself independently of the rest. A third species is found resembling *Carchesium* except in one respect. In this animal, *Zoöthamnium,* there is a common muscle extending through the stalk and its branches. When this muscle contracts, all the members of the colony contract simultaneously.

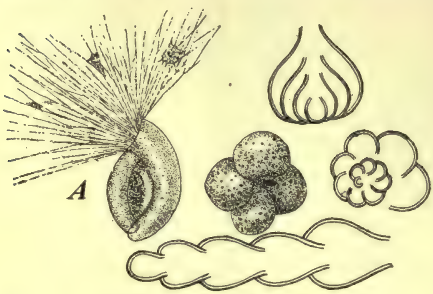

FIG. 40.—COLONIES OF UNICELLULAR ORGANISMS MADE UP OF SEVERAL CELLS ATTACHED TOGETHER

A, an animal with its pseudopodia protruding; in the other specimens only the shell is visible. These animals belong to the group of *Forminifera,* whose shells form chalk cliffs and limestone rocks.

These three animals are evidently closely related; but *Vorticella* is a true unicellular animal, *Carchesium* a cluster of independent cells attached together, and *Zoöthamnium* a similar colony in which the members are not wholly independent but have a vital connection.

There are many other animals which are in a similar way made up of colonies of cells, alike in structure and function. Several of these are shown in Figure 40. In all cases the animals start their life as single cells which become colonies by the method of incomplete division. All these are commonly classed among unicellular animals and called **Protozoa** (Gr.

protos = first + *zoon* = animal), although they are not strictly unicellular.

The same principle is illustrated by many of the lower plants, of which a single example will be given.

Ulothrix.—One of the common fresh-water pond scums, found everywhere in ditches by the roadside, is made of a green plant, *Ulothrix;* Fig. 41. *Ulothrix* consists of a long, slender thread formed by a row of nearly cylindrical cells, placed end to end; Fig. 41 *A*. The individual threads are barely visible to the naked eye. In each one of these cells may be seen green coloring matter, *chlorophyll* (Gr. *chloros* = green + *phyllon* = leaf), and each cell contains a nucleus. The cells are identical from one end of the thread to the other, differing only slightly in size, and each of them is capable of carrying on all the functions of life independently.

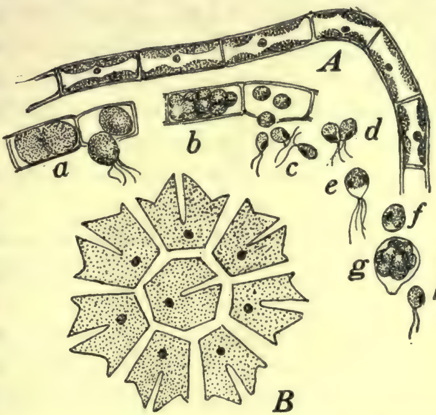

Fig. 41.—Plants made up of colonies of single cells

A, *Ulothrix*. *a*, shows the process of multiplication by the formation of zoöspores; *b* to *f*, show the formation of sex cells, their conjugation with each other; *g*, their subsequent division into spores; *h*, a single spore which grows into a new thread, like the original shown at large *A*. *B*, Pediastrium.

The reproduction in *Ulothrix* is interesting; and, like some organisms already studied, it shows two quite distinct methods. The first and simplest is as follows: The contents of one of the cells breaks up into several parts, which, after a time, escape upon the bursting of the plant's cell wall. As they come out, each is seen to be provided with four little flagella and is thus enabled to swim. They are called **zoöspores** (Gr. *zoon* = animal); Fig. 41 *a*. After swimming for a time they settle down, lose their cilia, and

each begins to develop into a new filament like that from which it originated. The growth into the new filament is by division; the cells after dividing remain attached together in the form of a long chain.

The second method of reproduction is by conjugation and reminds us of that in *Pandorina.* In this case, the contents of some of the cells break up into a large number of parts instead of a small number, and these, by the bursting of the cell wall, are finally liberated into the water; Fig. 41 *c.* They are then found to possess two flagella, instead of four like the zoospores, and by means of these they swim around. These small spores are, however, unable to grow into new threads.* After the spores have been swimming about for some time they come in contact, as shown in Figure 41 *d*, and fuse together, the fusion being identical with that already described in *Pandorina;* see page 74. There are thus formed conjugation spores known as the **zygospores** (Gr. *zygon* = yoke). These zygospores, after a time, produce by division several more spores which, upon becoming free, soon begin to divide and grow into new filaments like those with which we started. This kind of reproduction is very similar to that of *Pandorina* and clearly suggests the sexual reproduction which occurs in higher organisms.

In the organisms thus described, we have examples which cannot properly be called unicellular, nor on the other hand can they be called multicellular; each one of these cells carries on by itself all the functions of the organism, whereas in multicellular organisms, as we shall presently see, the different cells have different functions to perform, and the cells that make up the individual are not all alike as they are in the forms already described. We must look upon the *Pandorina* and *Ulothrix* as intermediate between the unicellular and the multicellular forms. In this way they illustrate the general

* Sometimes, however, they do grow into very short threads which are much smaller than the original.

biological principle that sharp lines dividing groups can hardly ever be drawn, and it is almost always possible to find intermediate forms connecting widely separate types.

True Multicellular Organisms.—Multicellular organisms are always made up of more than one cell; but the fact that they consist of many cells is not enough to define them accurately. A brief account of the manner in which multicellular organisms develop will explain the meaning of the term. In all cases they begin as a single cell, which may be either an egg or a spore. This cell divides into two parts, these into four, and so on, the number of cells increasing indefinitely; but after dividing, the cells remain attached instead of separating. After a while some of the cells assume a variety of types, *i.e.*, they become **differentiated** in form and function, and play different parts in the life of the organism. Such a differentiation of cells occurs in all true multicellular organisms. Hence we may define a *multicellular organism as one composed of many cells which show a differentiation in structure and function.*

With this differentiation of cells, **tissues** appear for the first time. Cells with similar structure and function are commonly grouped together, to form a tissue. The cells with special contractile power, for example, form *muscle tissue;* cells with power to secrete bone form *bony tissue;* and those in which conductility and irritability are particularly developed are grouped together to form *nervous tissue;* and so on. Tissues are, of course, impossible among unicellular organisms, but universal among multicellular organisms.

With the multiplication of cells and their differentiation, there also appears the formation of **true organs.** Among the unicellular animals and plants there may be certain parts of the cell, like the mouth and nucleus, set apart for certain functions, and these are, to be sure, cell organs. But they are not organs in the sense in which the term has been used among the multicellular animals, where groups of cells, usually of various kinds, are aggregated to form distinct parts with

definite functions, so that an organ contains several tissues grouped together to form a complex structure.

In the study of multicellular organisms, which follows in the later chapters, it will be seen that some of them have only a few simple organs, while others have many complex organs. Those which are of simple structure and have few organs we call **low organisms,** while by **high organisms** we refer to those whose structure is complex.

PENICILLIUM, A SIMPLE MULTICELLULAR PLANT

As an example of a multicellular plant with very slight complexity, we will study one of the common molds, which may be found growing upon almost any moist food the world over. It may usually be obtained in abundance by placing a bit of bread or a slice of lemon in a dish, covering it so that it will be kept from drying, and allowing it to remain in a warm place for a few days. The object will soon become covered with a mold (*Penicillium*) which after a day or two assumes a greenish-blue color. This organism is somewhat difficult to study under the microscope because it is so massed together that special methods have to be taken for preparing the specimens. The best method is to plant some of the spores upon a little jelly which has been hardened on a glass slide, and then study the spores under the microscope every day and notice the method by which they sprout and eventually form the complete plant.

Structure.—The structure of *Penicillium* may best be understood by studying Figure 42. It is made up of a mass of delicate, branching threads, extending in various directions. These threads are white or colorless and very minute. In the common species of *Penicillium* they are hardly visible to the naked eye, although in some species of molds they are slightly larger, and in others they are large enough to be plainly seen. These threads, which are known as the **mycelium** (Gr. *mykes* = fungus), have the function of assimilation, and absorb nourish-

ment from the substance upon which the molds are growing. Although the threads are very delicate, they can by growth force their way through the substance upon which they are feeding until they penetrate into the bread, or slice of lemon,

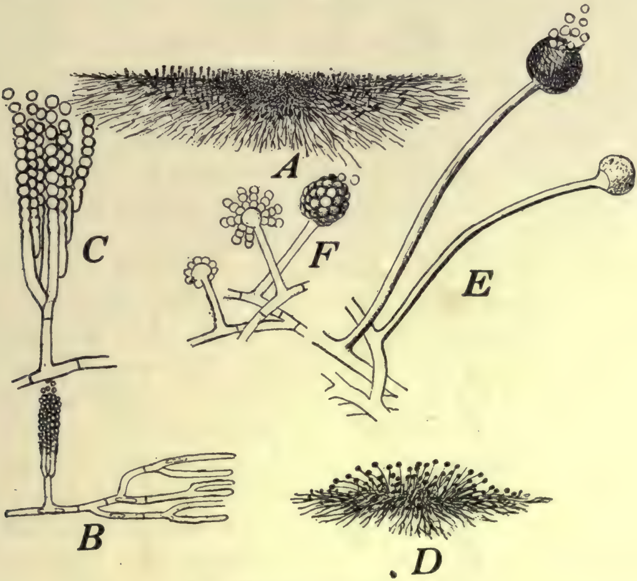

FIG. 42.—VARIOUS MOLDS

A, a colony of *Penicillium*, showing the fruiting spore-bearing masses arising from the mycelium; *B*, a bit of the colony more highly magnified; *C*, one of the fruiting masses, forming spores; *D*, a colony of *Mucor; E*, the sporangia of *Mucor*, with the spores emerging, and showing also the mycelium below not divided into cells; *F*, a bit of the colony of *Aspergillus*, showing a third method of formation of spores.

or decaying apple, for some distance, and the material thus becomes permeated with the mycelium. Careful study of the threads of this mycelium with a high magnifying power shows that they are made up of many cells. Cross partitions divide the threads at intervals and separate the consecutive cells; Fig. 42 *B*. The contents of each cell include protoplasm and a nucleus. There is no differentiation of the cells, all in

the mycelium being essentially alike, although a single plant may contain hundreds of these cells in its growing, branching mycelium.

Reproduction.—The only noticeable differentiation of cells that is seen in *Penicillium* occurs after the plant has grown for a few days and is ready for multiplication. There may then be seen arising from the mycelium minute branches that extend vertically into the air instead of growing horizontally over the surface of the object upon which the mold is nourishing itself. These rise from the mycelium, simply as branches, and are known as **aerial hyphæ** (Gr. *hyphé* = web); Fig. 42 *B* and *C*. The ends of these hyphæ branch into a number of finger-like processes, which extend vertically, parallel with each other, as shown at *C;* after a time these branches divide by constriction into rows of minute balls. These little spheres eventually break off from the plant and then, blown by the wind, are scattered far and wide. Each of them is capable, under proper conditions of moisture and temperature, of developing into a new plant. They are evidently **spores,** this particular kind of a spore being named **conidia** (Gr. *konis* = dust). The conidia are bluish in color and they cause the mold, which is at first white, to assume a distinct blue tinge, giving to this plant its common name of *blue mold.* They are extremely light and may be blown for a long distance before settling to the ground. Whenever they do settle upon any moist place they germinate; each spore produces a new thread which in the course of a few days becomes a new, branching mycelium and thus forms a new mold. The conidia produced by a single plant are very numerous and so light that they may be carried for a long time in the air. Indeed, the air is at all times more or less filled with them, in summer and winter alike; and it follows that any moist material which will furnish them with food, like bread, or pieces of lemon, or the surface of any fruit, if exposed to the air for a short time, will be sown with these little spores, and in a few days will begin to show signs of molding. So

widely scattered are these floating mold spores that it is hardly possible to expose any moist organic substance even, for a few minutes, without its becoming inoculated with some of them and showing, a few days afterwards, the growth of molds upon its surface.

Penicillium has a second method of multiplication which is rarely seen. It occurs only under special conditions which are not understood, and it has not been observed by many botanists. It consists in the formation of minute sacs, within which spores are formed, usually four or eight in number. These sacs are known as **asci** and the spores are **ascospores.** Eventually the sacs burst, the spores come out and are then capable of developing into new plants. This method of forming spores is evidently similar to that already described in *Yeast* (see Fig. 32 *s*), and shows that yeast is closely related to the molds. The same method of spore formation is found in a large number of other plants (lichens, cup fungi, etc.) and is used as a basis of classification for a class of *Fungi* called **Ascomycetes** (Gr. *ascus* = sac + *mykes* = fungus). It must be noted, however, that not all of the molds form spores in this way. The one shown in Figure 42 *D* has a method of reproduction by conjugation.

OTHER SPECIES OF MOLDS

Molds are very abundant in all parts of the earth wherever there is much moisture, and any bit of organic material left to itself will be sure to show signs of their growth in course of time. Many species of molds, which to the naked eye closely resemble each other, may be distinguished by careful microscopic study. In all cases the plant is a branching, colorless mycelium, similar to that described in *Penicillium.* In a few species, however, the mycelium is not divided into cells by partitions, as in *Penicillium,* but the whole thread forms one continuous mass called a *syncytium;* Fig. 42 *E.* The chief method by which the molds are distinguished from

each other is not by the structure and shape of the mycelium, but rather by their method of producing spores. *Penicillium* is one of the more common, but there are many other species in which the spores are produced by different methods. Three of these methods of spore formation are shown in Figure 42 *C*, *E*, and *F*. In some cases the spores are formed in a sac called a **sporangium,** as at *E*. In others they are borne upon a globular head, not inclosed in a sac; see *F*. Other species show various methods; but in all cases the method of spore formation is quite distinctive, and a careful microscopic study of the different forms makes it possible to separate them into species according to their methods of producing spores.

Molds play a very important part in the life processes in nature. The term *mold* is not a proper scientific designation for these plants, but a popular name, covering a variety of plants of similar form and structure, but with many different botanical relations. That they belong to different groups is proved by the fact already mentioned that they have different methods of reproduction, some of them forming ascospores, while others form spores by a process of conjugation, which, as we shall learn later, is a type of sexual reproduction.

LABORATORY WORK

The laboratory work that can be done by an elementary class upon karyokinesis is very limited. Mounted preparations should be furnished by the instructor. For this purpose the young growing root tips of *Podophyllum* are excellent. If these are collected in the spring and carefully preserved, sectioned, and stained in iron hæmatoxylin, they will show all stages of cell division. Longitudinal sections are best, and they should be studied with a 1/12 immersion objective to make out the details. By patient study of a few sections thus prepared the various steps in karyokinesis may be made out.

If the instructor can furnish other examples of dividing cells the student should make comparisons. Many tissues of animals and plants may be utilized.

Carchesium.—Colonial forms of *Vorticella*-like organisms, either *Carchesium* or *Zoöthamnium*, may usually be found in aquaria in which various fresh-water plants are kept. The dishes which have been prepared for the culture of *Amœba* and *Paramecium* will frequently show them. If they are obtainable they should be studied. No special methods are necessary, the colonies being small enough to be placed under a cover glass and studied alive. Staining with methylene green is useful to bring out the nuclei.

Ulothrix or Spirogyra.—One of these forms should be studied as an example of filamentous plants. Either of them may be found in ponds or ditches by the roadside. They are to be studied without any special preparation, the fresh form showing most points perfectly well. The shape of the cells and of the chlorophyll bodies should be noticed. The nucleus may usually, though not always, be seen without any treatment. A little glycerine added underneath the cover glass will cause the protoplasm to contract from the cell walls. Staining with methylene green will show the nucleus if it has not been seen without this. If material is at hand to show the conjugation, it is desirable to have the student study threads of conjugating *Spirogyra* and compare with the conjugation of *Paramecium* described in the text. The reproduction of *Ulothrix* by formation of spores is so difficult to obtain that it is impractical to furnish material to a class for study.

Penicillium and Other Molds.—Molds may be easily obtained by allowing bits of lemon, banana, bread, etc., to remain for a few days in a closed jar in a warm place. The general appearance of the molds can be studied on the surface of these articles. For a more careful study it is necessary to study the colonies growing from spores. A simple method is as follows: Prepare a culture medium from dried beans by placing a pint in about twice as much water as is necessary to cover them. Allow to stand 12 hours and add enough water just to cover the beans. Then strain off the liquid from the beans and filter. To the filtrate add 1% of agar and boil so as to completely dissolve the agar. Place the material in test tubes, about 10 c.c. in each, and plug the mouths of the tubes with cotton. Place in a wire basket and sterilize by steaming for three-quarters of an hour on three successive days. To use this culture medium, melt several of the tubes of agar and pour each into a petri dish, allowing the agar to harden. When thoroughly hard, remove with a platinum needle a minute quantity of the spores, which appear on the mold on the lemon or bread, and just touch the surface of the agar with the spore-laden needle tip in several places. This will sow the spores. Place the petri dish (covered to prevent drying) in a warm place. This dish may then be studied from day to day by putting it under a microscope, and the sprouting of the spores, the

growth of mold colonies, and their production of spores can be followed in detail. Several kinds of mold will usually start to growing on the lemon, etc., and may be distinguished by their color. The different species will show differences in spore formation. Sketches of the colonies and their method of spore formation should be made. The type which will be most commonly found are *Penicillium*, *Aspergillus*, and *Mucor;* Fig. 42.

CHAPTER V

THE CASTOR BEAN, A COMPLEX MULTICELLULAR PLANT

THE plants hitherto mentioned do not possess flowers and belong to what are called the flowerless plants or **Cryptogams** (Gr. *cryptos* = concealed + *gamos* = marriage). As an example of the higher multicellular plants we will describe one of those producing true flowers, *i. e.*, one of the flowering plants or **Phanerogams** (Gr. *phaneros* = open + *gamos*). For this purpose we will study the castor bean.

THE CASTOR BEAN (*RICINUS COMMUNIS*)

The **castor bean** (*Ricinus communis*) is the plant from which castor oil is obtained; it is also used as an ornamental foliage plant on account of its large, beautiful leaves. Other plants may serve for this study, but this one illustrates especially well the structure of the higher plants. The seeds may be obtained at seed stores and will readily sprout in moist sawdust.

FIG. 43. — A YOUNG SEEDLING OF THE CASTOR BEAN, THREE WEEKS OLD

s, the stem; *r*, the roots; *c*, expanded seed leaves; *p*, permanent leaves.

GROSS STRUCTURE

Figure 43, which represents a young seedling of the castor bean about two weeks old, illustrates the general structure of other multicellular plants, since the higher plants are essentially alike in

this respect. It consists of a stem connecting two expanded surfaces, the one ending in the leaves, and the other dividing under the soil into fine rootlets which bear root hairs. Plants obtain their food partly from the air and partly from the soil, and this explains why they expand their branches into leaves in the air, and their roots into root hairs in the soil. The stem of the plant serves chiefly as a connection between the leaf and the root and as a support for the branches and leaves.

STRUCTURE OF THE STEM

The structure of the stem may best be understood by beginning with the examination of a cross section of a young stem, shortly after it has emerged from the seed; see Fig. 44.

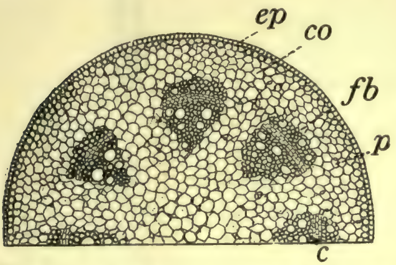

FIG. 44.— A SECTION ACROSS THE STEM OF THE SEEDLING

fb, the fibrovascular bundle; *co*, the cortex; *ep*, the epidermis; *p*, the general fundamental cells.

Fundamental Cells. — The bulk of the stem consists of a mass of approximately round cells, which are called **fundamental cells,** *p*. These cells are largest toward the center of the stem and grow smaller toward the outer edge. The large cells in the center form the **pith.** On the outer edge of the stem is a single layer of small rounded cells forming the **epidermis** (Gr. *epi* = upon + *derma* = skin), *ep*. Just beneath the epidermis are several irregular rows of cells, larger than the epidermal cells, known as the **cortex** (Lat. *cortex* = bark), *co*. At this stage the cortex on its inner edge is not very sharply marked off from the cells which fill the center of the stem, and form the pith.

Fibrovascular Bundles.—A short distance within the cortex will be found several groups of especially marked cells, *fb*,

known as **fibrovascular bundles** (Lat. *fibra* = fiber + *vas* = vessel). In the young stem there is a row of eight to ten of these groups, arranged to form a ring a short distance beneath the epidermis. The bundles do not actually touch each other, but the cells of the pith and the cortex are connected.

Structure of a Fibrovascular Bundle. — Figure 45 shows a highly magnified view of a cross section of one of these fibrovascular bundles. It consists of three parts:—

1. Running across the middle are several rows of small thin-walled cells known as the **cambium layer,** *c* (Lat. *cambire* = to exchange). These cells are full of active protoplasm and are the chief growing cells of the stem.

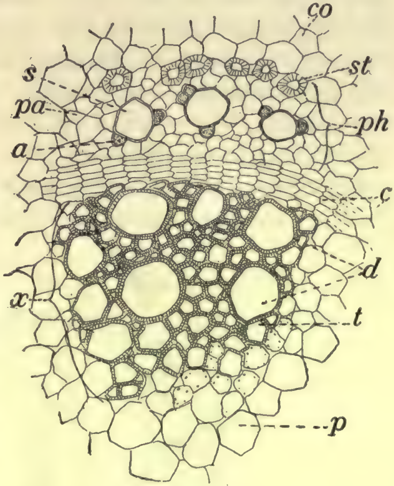

FIG. 45.—A HIGHLY MAGNIFIED SECTION OF A FIBROVASCULAR BUNDLE

a, accompanying cells; *c*, cambium layer; *co*, cortex; *d*, ducts; *pa*, parenchyma; *s*, sieve cells; *t*, tracheids; *x*, is the xylem; *ph*, the phloem part of the bundle; *st*, stereome cells.

2. On the inside of this layer, and therefore toward the pith, is the **xylem,** *x* (Gr. *xylon* = timber), a somewhat triangular mass of cells, the walls of which are thicker than those of the cambium. Among them may be seen at least two kinds of cells; one of small size but with very thick walls forming the **tracheids** (Gr. *trachea* = windpipe) or **wood** cells, *t*, and the other of larger size with relatively thin walls, forming the **ducts** or **vessels,** *d*.

3. On the outside of the cambium, and therefore toward the epidermis, is a somewhat irregular mass of cells called the **phloem** (Gr. *phloios* = inner bark), *ph*, within which may be

seen four kinds of cells. There are a few large cells called **sieve cells,** *s*, and near them some small cells called the **accompanying cells,** *a*. Other cells still smaller and with thin walls form the **parenchyma** (Gr. *para* = beside + *en* = in + *chein* = to pour), *pa*, and a few cells, with very thick walls, are called the **stereome cells** (Gr. *stereos* = solid), *st*. The cells of the cambium do most of the growing; as they multiply they produce new cells both on their inner and their outer edge, causing the bundles to increase in thickness by additions between the xylem and the phloem.

Figure 46, a longitudinal section through a bundle, shows the real shape of the cells. The cambium layer is composed of slightly elongated cells with square ends. Each of these cells contains protoplasm and a prominent nucleus, differing in this respect from the majority of the cells of the bundle, which are empty and represent only the cell walls from which the protoplasm has been removed. The xylem cells of the bundle, forming the wood proper, show several types. The large **ducts** have peculiarly marked cell walls. Some of them show rings forming thickenings on the inside of the cell wall, or the thickenings may take the form of a spiral, *sp*. Other ducts show dots or pits and various peculiar markings, *d*. The smaller cells, the **tracheids,** *t*, are much narrower than the ducts, but have relatively thicker walls. Some have square

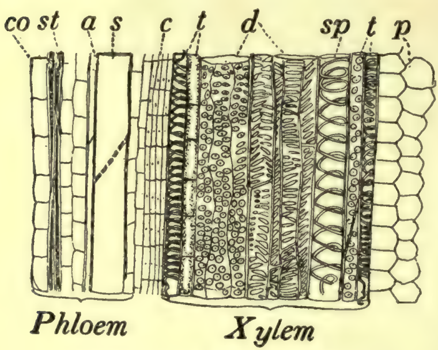

FIG. 46.—LONGITUDINAL SECTION OF A FIBROVASCULAR BUNDLE

a, accompanying cells; *c*, cambium cells; *co*, cortex; *d*, ducts; *p*, pith; *s*, sieve cells; *sp*, spiral ducts; *st*, sterome cells; *t*, tracheids or wood cells.

ends and others have ends tapering to a point, the cells dovetailing to form the hard, resisting part of the stem; the phloem outside the cambium layer also contains several kinds of cells. Some of them are large and have oblique ends which are perforated by apertures that place one cell in communication with the next above and below. Because of these openings, these cells are called **sieve cells.** It is through these cells that the food supply is transported through the plant from the leaves. Close to the sieve cells are smaller cells, the **accompanying cells,** *a*, which are long and slender. The phloem also contains many rather narrow cells with square ends called **parenchyma cells,** and a few small, short cells with very thick walls known as **stereome cells.**

The same longitudinal section shows that the pith, *p*, is made of short, square cells with very thin walls. Evidently the pith is a soft tissue and the strength of the stem is due to the hard and resisting fibrous cells in the bundles. Outside of the bundles, directly beneath the epidermis, it will be seen that the cells of the cortex, *co*, are much like those of the pith, hardly longer than they are broad, with thin walls and square ends.

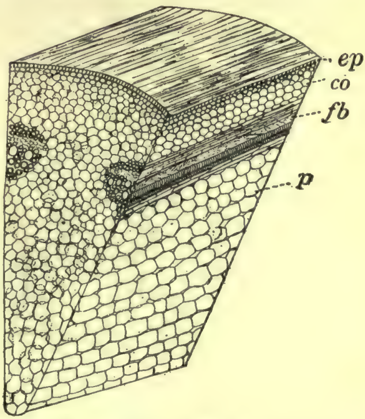

FIG. 47.—PERSPECTIVE VIEW OF A PIECE OF A YOUNG STEM, SHOWING THE FIBROVASCULAR BUNDLE EXTENDING LENGTHWISE IN THE STEM FOR SUPPORT

co, cortex; *ep*, epidermis; *fb*, fibrovascular bundle; *p*, pith.

The relation of the fundamental cells to the fibrovascular bundles is better shown in Figure 47, which shows how the bundles extend through the stem and strengthen it. The bundles evidently consist of very different material from that found in the pith

and cortex. They are mostly long, narrow cells with comparatively thick walls, which are hardened by the deposition of woody substance. The name fibrovascular is appropriately applied, since they are principally made up of fibers mixed with vessels. The strength of a stem depends upon the density of these bundles, and the thickness of the walls of the tracheids.

Of all this mass of cells only a few are filled with living protoplasm. The cambium cells are always alive and the sieve cells may contain protoplasm. The other cells contain protoplasm when they first form, but when they are fully grown most of them are only the empty cell walls. This is particularly true of the wood cells of the xylem. Protoplasm is more usually found in the phloem and the cortex than in the true wood.

Arrangement of Bundles in an Older Stem.—An examination of a slightly older stem shows that the bundles increase in width and finally fuse. In Figure 48 it will be particularly noticed that the cambium layer of one bundle has grown until it comes in contact with the cambium layer of the next, and thus forms a cambium ring extending around the stem a short distance within the cortex separating the outer portion of the stem, which is now called the **phloem** or **bark,** from the inner part, the **xylem,** or wood proper. Later the other parts of the bundles fuse, forming a complete ring of woody tissue and a complete ring of bark separated by the cambium.

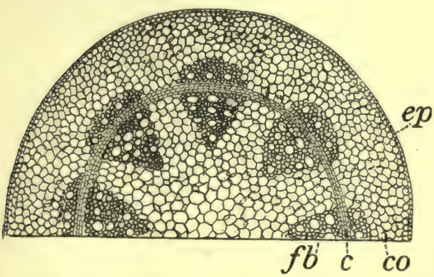

FIG. 48.—CROSS SECTION OF AN OLDER STEM, SHOWING CAMBIUM FUSED TO FORM A COMPLETE RING, *c*

(In other respects as in Fig. 43.)

Remembering that this cambium layer is made up of actively growing cells, it is easy to see how a stem of this kind may

increase in size. As the cells of the cambium layer divide, new cells are formed between the bark and the wood of the old bundles. Some of these new cells are formed inside of the cambium layer, and outside of the xylem, as shown diagrammatically in Figure 49. Other cells are formed on the outside of the cambium and inside of the old phloem layer. These new cells soon assume the form of new wood cells, new tracheids or ducts on the inside; while those outside the cambium assume the form of sieve cells, parenchyma, etc. It thus comes about that the plant is producing new wood cells in the form of a layer outside the old wood ring, and new phloem cells in a layer inside the old phloem ring. The wood grows by additions upon its outer surface and the bark by additions to its inner surface. Since the cambium forms a complete ring, this method of growth evidently will produce a complete ring of wood around the stem, and since the cambium cells continue to produce new cells during the whole of their active life, they will continue to add new layers of wood on the outside of the old wood. The wood ring, which at first is only a thin layer just inside the cambium, becomes thicker and thicker as the growth continues. As it becomes thicker, the stem, of course, increases in diameter, and, since the cambium always remains on the outside of the wood, the stem may keep increasing in size as long as the cambium cells are able to develop new cells to be deposited as wood cells on the outside of the old wood. In the same way the cambium deposits masses of cells on the inner side of the phloem of the bundles,

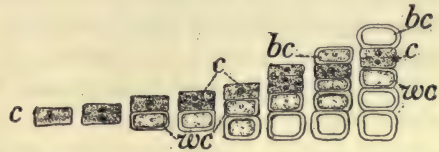

FIG. 49.—DIAGRAM SHOWING THE METHOD BY WHICH THE CAMBIUM LAYER PRODUCES WOOD CELLS ON ITS INSIDE AND BARK CELLS ON THE OUTSIDE

bc, the cells of the bark;
c, cambium cells;
wc, the wood cells.

and the bark also increases in thickness by growing on its inner side. This growth is, however, not so vigorous as is that of the wood, and the bark does not increase in thickness so much as does the stem. Since too the new cells of the bark are deposited on the inner side, the older parts of the bark must stretch to cover the increasing diameter of the growing stem. When a stem becomes of considerable size the outer bark will be found to be rough and broken by the expansion of the stem which it covers.

Some plants, which have but one year's growth, form a single ring of wood as described, and die at the close of the season. Other plants, like large trees, do not die, but live year after year; and each year the cambium layer adds new masses of cells outside of those previously existing. In plants that live in regions where the climate changes with the seasons, the cells formed by the cambium layer are larger at certain seasons of the year than at others. In temperate regions, the wood cells formed in the spring are larger and relatively thinner walled than those formed later in the season. During the winter, growth ceases entirely; but as soon as spring comes again, a new layer of large cells will be deposited on the outside of the last ring that was deposited in the fall. The result of this is a series of rings easily recognized when a cross section of a stem is made; Fig. 50. Since each ring indicates ordi-

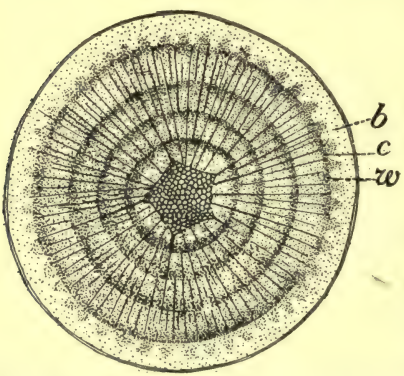

Fig. 50.—Section across an exogenous stem of four years' growth, showing the four rings of wood

b, bark;
c, cambium layer;
w, wood ring.

narily a year's growth, the age of the plant may be determined by counting the number of rings. Such rings are rarely visible in the bark, although the bark also increases in thickness by layers added to its inner side.

From this description, it is evident that the growing part of the stem is the cambium layer and that the stem of the plant is capable of continuing its life only as long as this cambium layer is intact. What is known as *girdling* a tree consists in cutting a ring through the bark around the tree in such a way as to destroy entirely the bark and the cambium layer; this effectually kills the tree because the cambium layer is destroyed, and unless there is a connection of living cambium between the roots and the leaves, the life of the plant cannot be maintained. It is also evident why the bark may be stripped away from the wood of the tree so readily. The inner edge of the bark comes next to the cambium; the cambium cells are thin-walled, full of soft protoplasm and easily broken, and hence the bark is easily separated from the rest of the tree at this point.

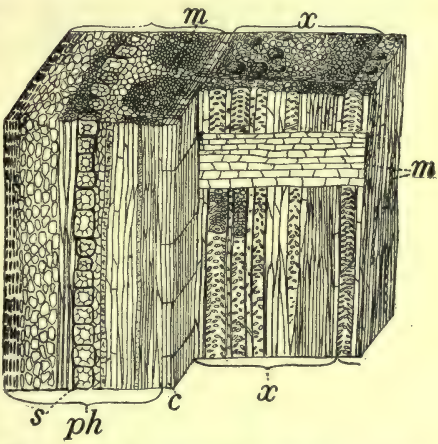

FIG. 51.—A PARTLY PERSPECTIVE VIEW, SHOWING THE RELATION OF THE PARTS IN THE STEM OF AN OAK

c, the cambium layer; *m*, medullary rays; *ph*, phloem; *s*, stereome cells; *x*, xylem.

Medullary Rays. — The cells in the vascular bundle extend up and down the stem. There are, however, other cells that run horizontally, extending from the center to the outer edge. These form what are called **medullary rays** (Lat. *medulla* = marrow); see Fig. 51. They probably serve for the trans-

ference of the material from the outer part of the stem toward the center, or the reverse. This type of stem is called an **exogenous stem** (Gr. *exo* = outside + *genes* = a producing), a name given to it from the fact that it grows by the addition of new layers of wood upon its outer side. Such a stem may increase enormously in thickness; some trees live for many hundreds of years and become several feet in thickness.

There is, however, another type of stem which has a different arrangement of the fibrovascular bundle. This is shown in cross section in Figure 52, which represents a cornstalk. In this section there is no ring of wood, the fibrovascular bundles are scattered irregularly through the stem, and there is no bark or true pith. Moreover, closer examination of these fibrovascular bundles shows that they do not have any distinct layer of cambium cells. As a result, they have no growing layer and are not capable of increasing in size. Such a stem is known as an **endogenous stem** (Gr. *endon* = within + *genes*), and belongs to a type of plants, like the grasses and bamboos, that grow tall and slender. Their stems are only a little larger at the bottom than at the top and do not materially increase in diameter. This type of stem forms a totally different group of plants from the first, differing in many respects in their leaves and flowers, as well as in their stem structure.

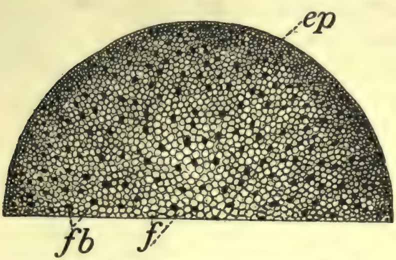

FIG. 52.—CROSS SECTION OF ENDOGENOUS STEM

ep, the epidermis; *f*, the fundamental cells; *fb*, the fibrovascular bundles scattered indefinitely through the stem.

STRUCTURE OF THE ROOT

The structure of the root of the castor bean resembles that of the stem, with some noticeable differences. A cross section shows that the **cortex** is very much thicker than it is in the

stem, and there is also a layer of cells on the inner side of the cortex known as the **endodermis**; Fig. 53. Within this are the **fibrovascular** cells fused together and showing little definition into cambium layer or fibrovascular bundles. The **pith** is reduced to a few cells in the center of the root. The tip of the root is always small and delicate, yet it must force its way through the hard soil. The end of the root contains delicate, thin-walled, growing cells, which would be injured in pushing their way. To protect them the tips of the roots are covered with what is known as the **root cap**; Fig. 54. This is a mass of rather hard corky cells which covers the delicate growing cells and protects them from injury as the root pushes its way through the compact soil.

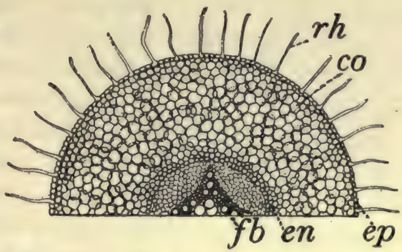

FIG. 53.—CROSS SECTION THROUGH A SMALL ROOT

co, the cortex; *ep*, epidermis; *en*, endodermis; *fb*, fibrovascular bundle; *rh*, root hairs.

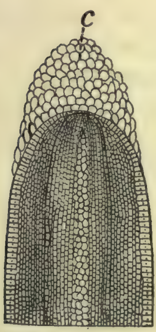

FIG. 54.—A SECTION THROUGH THE TIP OF A ROOT

Showing the root cap, *c*.

FIG. 55.—TIP OF A ROOT

Showing the abundance of root hairs.

On the outside of the rootlets, chiefly near their ends, are the most important structures connected with the root, the **root hairs**; Figs. 55 and 56. They are very delicate threads which grow out of the side of the root and radiate from it into the soil. Figure 56 shows a more highly magnified view of some of these hairs, showing that it is a single cell arising from the epidermis of

the root. The root hairs are present in immense numbers on the fine, delicate growing root tips, and grow in all directions into the soil. They are thus brought into close contact with particles of soil and serve the plant as an organ for absorbing water. All of the nutrition that a plant derives from the soil is drawn through these root hairs, which are closely connected with the cells on the interior of the root; so that liquids absorbed by the hairs pass readily into the substance of the root itself. From here they pass from cell to cell, and eventually find their way to all parts of the plant. The root hairs, constituting the absorbing organ of the plant, are of great functional value. If a plant is forcibly pulled out of the soil, all of the root hairs are torn from the root and left attached to the particles of the earth. If, however, the whole plant is removed from the ground and the soil is carefully washed from the roots, the root hairs may be found still attached to the rootlets, and may show grains of sand attached to the root hairs.

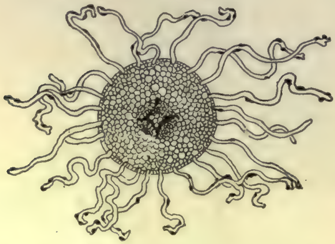

FIG. 56.—CROSS SECTION OF A MINUTE ROOT

Showing the relation of the root hairs to the cells of the root.

STRUCTURE OF THE LEAF

A complete leaf consists of three parts: The broadly expanded **blade**; the contracted stem or **petiole**; and two little appendages called **stipules** attached to the base of the petiole where it is connected with the stem. The stipules are not present in all leaves and are not found in the castor bean. Running from the top of the petiole out into the blade are a series of fine **veins**; in some plants they run in a parallel direction (*parallel-veined leaves*), and in others they branch profusely into many small twigs (*netted-veined leaves*).

Minute Structure of the Leaf.—A section across the petiole of a leaf shows a structure similar to that found in the stem of a plant, except that there is no regular ring of fibrovascular bundles and no cambium layer. In this petiole may be seen several fibrovascular bundles separated from each other; and if these are traced down to the stem from which the petiole of the leaf arises, they will be found continuous with the fibrovascular bundles of the stem. Followed into the blade of the leaf, these bundles are found to pass out into it and form the veins. Thus the veins of the leaf are simply an extension of a few of the fibrovascular bundles that come from the stem. Being hard and tough, they give sufficient rigidity to the leaf to support the softer parts, which are the active portions of the leaf structure.

Microscopic Structure of the Blade.—A cross section through the blade of the leaf is most instructive, since it is in the blade

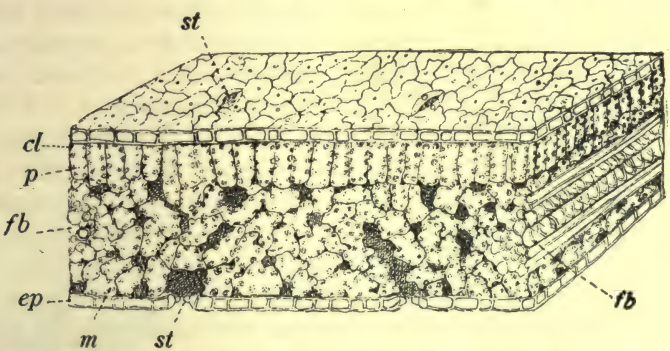

FIG. 57.—CROSS SECTION OF A BIT OF THE BLADE OF A LEAF

cl, chlorophyll bodies;
ep, epidermis;
fb, fibrovascular bundles;
m, mesophyll cells;
p, palisade cells;
st, the stomata.

of the leaf that the most important function of plant life is carried on. Upon its upper and under surface there are single layers of cells, the **epidermis**; Fig. 57 *ep*. These are made of small, irregular cells, closely compacted together and possessing

a hard cell wall forming a layer that is impervious to liquids and even to gases. They form a covering of the leaf which prevents the entrance of water, and protects it from too great a loss of water by evaporation. Through the epidermis are numerous openings known as **stomata** (Gr. *stoma* = mouth), *st,* that serve as breathing pores. If a bit of the epidermis is stripped from the leaf, it will appear as shown in Figure 58. The cells of the epidermis are irregular in shape, due to the irregular growth of the leaf, and among them are numerous pores. Each pore is surrounded by two crescent-shaped cells, **guard cells,** so related to each other that the pore itself lies between the two crescent cells. The guard cells are capable of expansion and contraction under different conditions. As they expand, they straighten out and close the opening of the stomata; and when they contract they shorten slightly and the opening of the stomata is enlarged; Fig. 59. In this way they can change the size of the breathing pores of the plant and thus regulate the amount of air that passes in and out of the leaf. These stomata occur in the epidermis of the petiole and all over the leaf, less abundantly on the upper side than on the under side. In the leaves of water plants, however, the stomata are chiefly on the upper side of the leaves, where they are in contact with the air when the plant

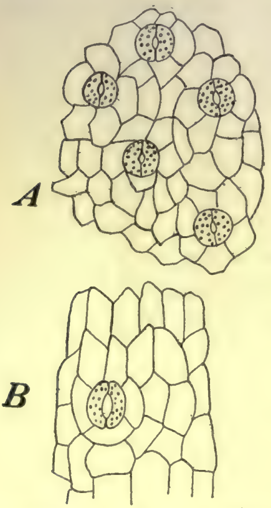

FIG. 58.— THE EPIDERMIS SHOWING THE STOMATA

A, from the leaf blade; *B*, from the petiole.

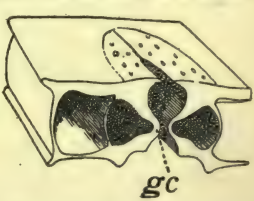

FIG. 59.— DIAGRAMMATIC CROSS SECTION OF A STOMA

gc, guard cells.

floats on the surface of the water. The shape of the stomata and guard cells varies slightly in different plants, but their structure is always essentially like that seen in the Figures 58 and 59.

In the middle of the leaf may be seen cross sections of the veins, which are typical fibrovascular bundles (Fig. 57 *fb*), composed of essentially the same kind of cells that we have found in the bundles of the stem. The rest of the substance of the leaf is filled with a loose mass of cells which are the active cells of the plant. Immediately under the upper epidermis is a layer of slightly cylindrical cells forming a fairly definite row. These are called the **palisade cells**; Fig. 57 *p*. They contain minute granules (*chloroplasts*) of green coloring matter called **chlorophyll** (Gr. *chloros* = green + *phyllon* = leaf), *cl*, and each contains protoplasm and a nucleus. Below the palisade cells are other cells more irregular in shape and more loosely packed. In this part of the leaf these cells are called **mesophyll cells** (Gr. *mesos* = middle + *phyllon* = leaf), *m*, and their shape is so irregular and they are so loosely packed that many air spaces communicating with the exterior through the stomata are left between them. These mesophyll cells are filled with active protoplasm and crowded with **chloroplasts** (Gr. *chloros* = green + *plastos* = molded). The intimate connection which these chlorophyll-bearing cells have with the air that enters through the stomata is evident from Figure 57, and is a matter of extreme significance, since these cells extract from the air the food from which the plant manufactures starch, the first step in the production of food for all animals and plants; see page 129.

The epidermis of the leaves of some plants has various other structures. Not infrequently it is prolonged into **hairs** of various shapes and sizes; sometimes these hairs have a little poison at their ends and then they constitute **nettle hairs.** The general function of the hairs is to protect the plant from injury by small insects and other animals.

REPRODUCTIVE ORGANS

The organs which are designed for reproduction are widely different in different groups of plants. Among the higher plants this function is carried on by specially modified branches known as **flowers.** Although the greatest variety is shown among the flowers of different plants, when compared they are readily seen to have the same general structure. The following description is not that of the flower of the castor bean, or of any other plant, but an ideal description of a typical flower, and in a general way applies to the flowers of all the higher groups of plants.

General Structure of a Flower.—A flower is always borne at the end of a stem; even although it appears to come from the side, when carefully examined it is found to be really on the end of a short, undeveloped stem arising from the side of the larger one. Indeed, a flower is itself a short stem bearing usually four rows of leaves; Fig. 60. The stem of the flower is called the **peduncle,** *p;* at its top it is frequently slightly enlarged to bear the several rows of leaves, this enlargement being known as the **receptacle,** *r*. The flower itself is composed of four rows of leaves so closely attached to each other that they appear to arise at the same point of the stem; careful study, however, shows that in all complete flowers the four different kinds of leaves are produced one row above the other.

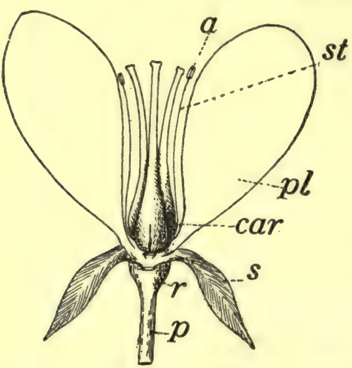

FIG. 60.—DIAGRAM SHOWING THE PARTS OF AN IDEAL FLOWER

a, the anther; *car*, carpels; *p*, peduncle; *pl*, petal; *r*, receptacle; *s*, sepals; *st*, stamens.

The Calyx composed of Sepals.—The lower row, which is on the outer side of the flower, is made up of small parts which are usually green and leaf-like in appearance. This row is known as the **calyx,** and the leaves of which it is composed are called **sepals.**

The Corolla composed of Petals.—Just above and within the calyx, in an ordinary flower, is a second row of leaves, usually larger than the calyx and of some brilliant color. This row of leaves is known as the **corolla** and the individual leaves as **petals,** *pl.* It is these colored petals that give the flower its brilliancy, and their function seems to be to attract the insects, that are useful to the flower in producing cross fertilization; see page 267. The calyx and corolla together are sometimes known as the **perianth** (Gr. *peri* = around + *anthos* = flower). In some flowers either the calyx or the corolla may be lacking, and in others both may be lacking. When only a single row of leaves is found in the perianth, it is customary to call it a calyx, irrespective of its shape and color, and such plants are usually spoken of as **apetalous** (Gr. *a* = without + *petalon* = a leaf).

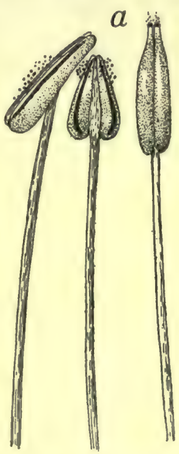

FIG. 61.—THREE STAMENS WITH DIFFERENT FORMS OF ANTHERS

a, showing methods of splitting open to discharge the pollen.

The Stamens.—Within the petals is a third row of leaves, the **stamens,** *st*, which, however, have almost wholly lost their resemblance to leaves. Each of these consists of a delicate stem, called the **filament** (Fig. 61), at the top of which are little sacs, usually two in number, which are known as the **anther,** *a*. Within these sacs are produced large numbers of spores, the spores in this case being called **pollen**; Fig. 62. The stamens are usually as many as the petals, although in some flowers there are two or three times as many, and in

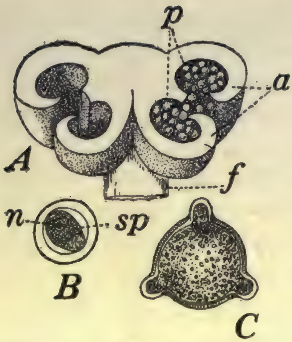

FIG. 62. — DETAILS OF AN ANTHER OF A FLOWER

A, section across the anthers, showing the four cavities with the pollen, *p*, enclosed; *B* and *C*, pollen grains; *n*, nucleus; *sp*, the pollen cell or microspore.

others some of the stamens disappear. Some flowers are entirely without stamens and are spoken of as **imperfect flowers.**

Carpels.—Within the stamens is the fourth and last row of leaves. In this case the parts have lost all resemblance to leaves and in ordinary flowers they would never be thought of as corresponding to leaves, unless carefully examined. The parts of this inner row are known as **carpels** (Gr. *carpos* = fruit); Fig. 60 *car.* Each carpel consists of three portions, a lower, somewhat expanded portion known as the **ovary** (Fig. 63 *ov*), and above this a more or less elongated, slender part, called the **style,** *s*, whose upper, slightly roughened surface is known as the **stigma,** *st.* These three parts form what is commonly called the **pistil.** It frequently happens that the number of carpels is less than that of the calyx, corolla, or stamens. Moreover, the carpels are often so fused together that it is impossible to count distinctly the separate carpels of which it is composed. When this occurs, there is found in the center of the flower what is known as a **compound pistil,** *i. e.*, a pistil made of several carpels fused together; see Fig. 63 *B*. But it is usually

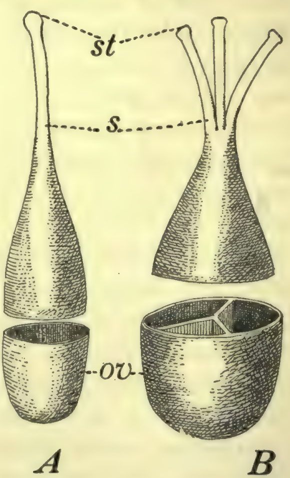

FIG. 63.—PISTILS

A, a pistil made up of a single carpel; *B*, a compound pistil made up of three carpels; *s*, the style; *st*, the stigma; *ov*, the ovary.

easy to perceive this condition in the pistil and to determine the number of carpels of which it is made. The pistil shown at Figure 63 *B* is evidently made up of three carpels, with fused ovaries, but remaining more or less separated from each other above. In some cases the style and stigmas, as well as the ovaries, are fused together, and it is more difficult to determine the number; but even in these cases we can easily distinguish in a compound pistil the number of carpels of which it is composed, by counting the number of rows of seeds in the ovary, there being usually one row of seeds for each of the carpels in the compound ovary.

In some flowers the carpels are entirely absent, and such a flower is called an *imperfect flower*. A **perfect flower** is a flower that has both stamens and pistils, and such a flower is capable of producing seeds. An **imperfect flower** is one in which either the stamens or the carpels are lacking, and such flowers are not alone capable of producing seeds.

Within the ovary are found the true reproductive bodies. These at first appear as several rounded masses called **ovules** (Fig. 64), within each of which is a single minute spore cell, *s*, corresponding to the spores which form the pollen. This spore never leaves the ovule, but undergoes a series of changes within the ovary which result in the production in each ovule of

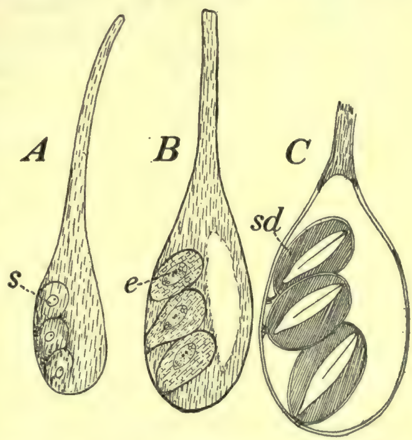

FIG. 64.—A LONGITUDINAL SECTION OF A PISTIL IN DIFFERENT STAGES OF DEVELOPMENT

A, showing the immature ovules with the enclosed spore, *s*; *B*, the older ovules, containing an egg, *e*; *C*, the ripened ovary with the seeds, *sd*, each containing a young embryo plant.

one or two **eggs**, *e*. As these spores produce eggs, which are the female reproductive bodies, we may speak of them as **female spores.** Older botanists, before their real nature was understood, called them by the name of *embryo sacs.* The small spores (pollen) produced in the anther, on the other hand, are spoken of as **male spores,** inasmuch as their function in reproduction is that of the male.*

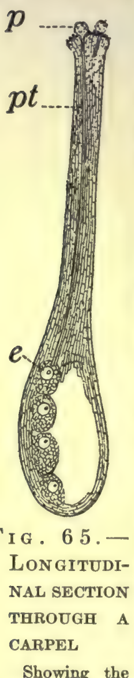

FIG. 65.—LONGITUDINAL SECTION THROUGH A CARPEL

Showing the pollen, *p*, attached to the stigma, and protruding, its pollen tube, *pt*, which has pushed its way through the style to the egg, *e*, enclosed in the ovule.

Fertilization.—The pollen grains, or male spores from the anther, are carried by some means to the stigma of the stamen. They are sometimes carried by insects, sometimes by wind, or by various other means. The stigma on the top of the pistil is usually rough and sticky, and the pollen grains readily adhere to it. In this position, the pollen grows and a long tube arises from each pollen grain and pushes its way down through the style and within the ovary; Fig. 65 *pt*. This tube is the **pollen tube.** In the meantime the female spore in the ovary has produced the egg. The pollen tube is attracted to the egg, and finally its tip comes in contact with it. Inside of this pollen tube is found one or more special cell nuclei which are carried in the tip of the growing tube and finally pass into the egg, fusing with it. This latter process is called **fertilization.**

The Seed.—After the egg, which is a single cell, has fused with the contents of the pollen tube, it divides, and in a few days produces a little multicellular plant. This plant, while still in the ovary of the pistil, develops a stem and one or more leaves; Fig. 64 *sd*.

*The pollen because of the small size, is also called a **microspore,** and the spore in the ovary, being larger, is called a **megaspore** or **macrospore.** The significance of this we shall notice in a later chapter.

After a few days it stops growing and becomes surrounded by a hard shell, and is now known as a **seed**; in this form, protected by its shell, it may remain dormant for some time. If any seed is carefully examined it will be found to contain a little plant, or **seedling,** with a stem and one or more leaves; Fig. 66. The leaves inside of the seed are known as **cotyledons,** and while they are true leaves they are different in shape and structure from the leaves which this same plant is to produce later when the seed has germinated; see Fig. 43.

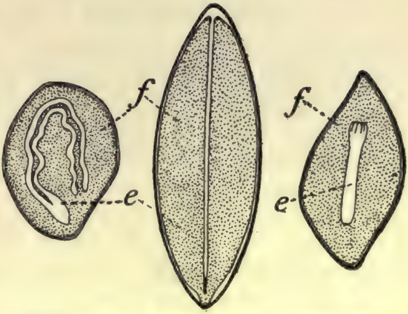

FIG. 66.—LONGITUDINAL SECTIONS OF THREE SEEDS

Showing the enclosed young plant or embryo, *e*, and food, *f*. In the middle figure, the food is deposited in the leaves of the embryo; in the two other figures the food is around the embryo.

There is also deposited in the seed, either around the seedling or within it, a quantity of food upon which the young plant can feed during the first few days of its life, before it can feed itself from the soil.

This whole process of fertilization, growth into a little plant, and the development of the shell around it to form a seed, occurs within the pistil of the flower. The flower in the meantime withers and the ovary increases in size to accommodate the growing seeds. Eventually, the fruit is broken open (*dehiscence*) and the seeds drop out. When this occurs the duty of the flower is over and all its parts decay, leaving the plant without flowers until the next season. From this description, it will be seen that there are in the flower at least four different kinds of reproductive bodies: the male spores, or *pollen;* the female spores, or *embryo sac;* the *eggs* which develop from the female spores and finally grow into seeds, and the *male nuclei* inside the pollen tube which fuse with the

egg. The relation of these different bodies to one another and to the general process of reproduction will be considered in a later chapter.

LABORATORY WORK ON THE CASTOR BEAN

Seeds may be obtained at almost any seed store. For the study of the seeds they should be soaked over night in water, which will soften them so that the outer covering may be removed and the seed readily dissected.

The study of the plant structure should be made from young seedlings. Soak the beans in water over night and then plant them in a box containing moist sawdust, covering the box with a piece of glass to prevent evaporation. Place the box in a warm place and water the seeds daily, keeping the sawdust quite moist. The seeds will sprout quickly and at varying periods of growth plants may be removed, the sawdust washed from their roots, and the plants studied as a whole.

For the study of the stem both cross sections and longitudinal sections should be made with a sharp razor, the piece of the stem to be sectioned being held between two bits of pith which are hollowed out to receive them. These sections may be mounted in water and studied directly, without any further preparation. Some points can be seen more satisfactorily by the use of various stains. It is best to begin with the study of a young seedling about two inches high, and to follow with older plants which will show the growth of the fibrovascular bundles and their fusion into a ring. All of the points mentioned in the text should be studied.

The study of the root is made in the same way. To obtain root hairs, it is better to sprout sunflower seeds by placing them, after soaking in water, between two layers of blotting paper in a covered dish, which should be kept moist and warm. After two or three days the rootlet of the young seedling will show a mass of root hairs. They should be examined through a lens without disturbing the seedling, and then one of the rootlets should be placed in a watch glass in water and examined with a microscope.

The epidermis of the leaf may be studied by stripping off with fine forceps a bit of the epidermis from the upper or under side of a leaf. Any plant will serve for this, and it is well to examine the epidermis of several different plants. The study should be made with a high power. The internal structure of a leaf must be made by cross sections. These are very difficult to make, and prepared, stained sections should be furnished by the instructor.

The stems of other plants showing annual rings of growth should also be studied in both cross and longitudinal sections. Twigs of the pine,

apple, or oak which show about three years' growth are satisfactory. The wood is hard to cut and is apt to injure the razor. It may be softened by soaking the stem in a mixture of equal parts of alcohol and glycerine. The stems should remain in this mixture for several days at least, and may be left in it for months without injury, and be ready for section at any time.

For the study of a flower any simple wild-flower may be used to show the general relations of the reproductive organs. A common *Trillium* is an excellent example. The grosser anatomy of the flower should be studied; sections should be made through the ovary both of a young flower and, if possible, of the fruit after the flowering is completed, in order to show the chambers of the ovary and the seeds with their attachments. The pollen should be examined with a microscope.

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CHAPTER VI

THE PHYSIOLOGY OF A TYPICAL PLANT

In order to carry on its life a plant must have an income of **matter** and **energy.** The problem of energy will be reserved for a later chapter: only a consideration of the relation of plants to their food and its utilization will be given here.

Plant Foods.—The income of an ordinary green plant is derived partly from the air and partly from the soil. It consists of: —

1. *Carbon dioxid* (CO_2), absorbed from the air by the leaves.
2. *Water* (H_2O), absorbed from the soil by the root hairs.
3. *Nitrates* or other *nitrogen salts*, absorbed from the soil by the root hairs.
4. *Phosphates, potash salts,* and other *minerals,* in small amounts, absorbed from the soil by the root hairs.

The carbon dioxid and water are absorbed by the plant in enormous quantities and constitute by far the largest proportion of their foods; the soil minerals, although absolutely necessary, are needed only in small quantities. Roughly speaking, the amount of material absorbed from the soil is represented by the ashes that are left after a plant is burned. All of the minerals are dissolved by the waters in the soil and absorbed in this form by the root hairs.

Ascent of Sap.—Since the foods are obtained through organs situated at the opposite ends of the plant, in order that they may be utilized they must be brought together, and since it is in the leaves that they are utilized, the water, containing the dissolved minerals absorbed by the roots, must be carried up the stem to the leaves. This **ascent of sap** is going on constantly during the activity of the plant and its rapidity is proportional to the activity of the processes going on in the leaves and buds.

The method by which the sap is carried up the stem is only partially understood; there are several factors concerned. One factor is **osmosis.** The water from the soil is absorbed by the root hairs principally through the physical force of **osmosis,** a force which is capable of causing some substances to pass, even against resistance, through the thin-walled root hairs, while others are rejected. An osmotic pressure is thus produced in the root, due to the absorption of liquids from the soil, and this forces a current up through the stem.

A second factor is the absorptive power of protoplasm. Living protoplasm has a strong **avidity for water** and absorbs it until it is saturated. If a plant were in absolute equilibrium, each bit of protoplasm would absorb all the water that it could obtain and a condition of rest would soon appear. If, however, a cell loses any of its liquid, it will have at once a stronger demand for water than before, and will tend to draw it away from neighboring cells that are more nearly saturated. Hence in a plant there will be a constant flow of water from saturated parts to those less saturated. In an ordinary green plant there are several processes that use up the water, all of them especially active in the leaves and growing buds at the top of the plant. These are as follows:—

1. Water is being used in the leaves to *manufacture starch.*

2. *New protoplasm* is being made in the leaves and in the growing buds, and this new protoplasm demands water.

3. Water constantly *evaporates* from the leaves through the stomata (*transpiration*). The extent of this evaporation varies greatly with the warmth and dryness of the air and also with the extent to which the stomata are opened. When there is abundance of water in the plant, the stomata are widely open and evaporation is rapid; but when the water is insufficient these pores partly close and evaporation is checked. On a warm day when the air is dry the evaporation is increased, but in a cool damp atmosphere it is lessened.

A third factor is **capillarity;** this is the same force that

causes oil to rise in the wick of a lamp. To what extent this contributes to the flow of sap is uncertain.

These factors combine to produce a lack of water at the top, and an excess in the roots, which produces a consequent tendency of the liquids in the plant to flow upward; the total result being a flow of the liquids from soil to root, from root to stem, and through the stem to the leaf and bud. The rapidity of this ascent of sap is directly proportional to the activity in the leaves and buds, since this determines the extent to which the water is used up. In warm bright sunshine the life processes in the leaves are vigorous, the stomata open, and the sap rises rapidly. At night the current is decreased, and in winter the processes practically cease, to be revived again when the warm sun of spring makes it possible for the cells in the leaves and buds to resume their activity. It is known that the water rises chiefly in the large ducts of the fibrovascular bundles, the spiral and ringed ducts serving for this purpose. It does not flow, however, in the cavities of these ducts, but rather in their walls, passing from cell to cell within the thick, but evidently porous, walls.

While these factors partly account for the rise of sap, they do not explain the actual force which lifts the water, rising as it does to the tops of the tallest trees. This is difficult to explain. It is generally thought to-day that the three forces above mentioned are sufficient for the process: (1) *Osmosis:* this forces the water from the soil, through the root hairs into the roots, and probably from cell to cell within the plant, up through the root and stem to the top of the plant. (2) *Capillarity:* this force causes liquids to rise inside of small spaces, and must play some part in the rise of water in the plant. (3) *Avidity for water:* the demand for water of the protoplasm at the top of the plant, above explained, is doubtless an active agent also in producing the flow of water from cell to cell up the plant. Whether these forces are sufficient to explain the ascent of sap we do not know; but at all events the plant

possesses no distinct circulatory organs, and it is believed that these physical forces are sufficient to account for the lifting of water from the soil to the leaves and buds.

Transfer of Substances Downward.—It is evident that there must be a transfer of material downward as well as an ascent of sap. As we shall presently notice, plants are engaged in making starch in their leaves, and this starch is certainly carried to all parts of the plant, since it may be stored in the underground parts. The starch in a potato, for example, is made in the leaves and hence it must be carried downward. The method by which the material is carried from the leaves downward is even less understood than the ascent of sap, although osmosis is undoubtedly one of the factors. It is known, however, that the starch is first changed to sugar and then dissolved in the liquids of the plant. It is also known that these materials then descend, not in the same cells in which sap is ascending, but in the large sieve cells of the bark (see Fig. 46), which are the cells chiefly concerned in the downward current. Since the bark is needed for this downward passage of food, we see another reason why the cutting of the bark away from the tree for a short distance, *girdling*, will in time kill the plant, since the food materials made in the leaves cannot then be carried to the roots and they will die for lack of nourishment.

PHOTOSYNTHESIS OR STARCH MANUFACTURE

By the process just described, the water, with the dissolved minerals, is brought to the chlorophyll cells in the leaves. These same cells are also in direct contact with carbon dioxid which is in the air and is brought into the leaf through the stomata. The chlorophyll-containing cells have the wonderful power of causing the carbon dioxid obtained from the air, and the water obtained from the soil, to combine with each other chemically to form a new product. The transformation is represented by the following equation: —

$$12\,CO_2 + 12\,H_2O = 2\,\underset{\text{(Starch)}}{C_6H_{10}O_5} + 24\,O + 2\,H_2O$$

It must not be understood that this equation is an accurate statement of what occurs, for we do not know the details of the building of starch from carbon dioxid. There is no doubt that the process is far more complex than is indicated by this simple equation. The building of CO_2 and H_2O into starch is not done by a single step as here represented, but in all probability by several steps. Moreover, the starch molecule is by no means a simple molecule as the formula $C_6H_{10}O_5$ indicates, but some multiple of this formula; how high a multiple we do not know, but probably with many times this number of atoms in the molecule. The above equation represents the ratio of the atoms but not their actual number. While the details of the method by which the complex molecule of starch is formed are not yet known to us, we do know that the essential features represented by this equation—namely, that CO_2 and H_2O are combined, that starch is manufactured, and that oxygen is set free—are in the main correct. This process is called **photosynthesis** (Gr. *photos* = light + *synthesis* = composition), and it is the only known method by which starch can be manufactured, chemists having hitherto been unable to make it by any artificial means.

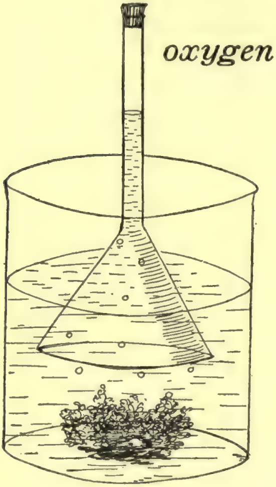

FIG. 67

Showing a method of demonstrating that a plant while growing eliminates oxygen gas. The plant is a green water plant, and the bubbles which arise from it and collect in the tube prove to be oxygen.

From the above equation it will be seen that while carrying on photosynthesis, a plant is using up carbon dioxid and at the same time liberating oxygen and producing starch. The oxygen is liberated in the form of a gas which passes from the plant into the atmosphere. The liberation of oxygen may be easily demonstrated by placing some kind of green water plant in a dish of water

and placing it in the sunlight. Minute bubbles of gas will soon make their appearance on the plant, which will rise through the water and pass off into the air. If these bubbles are collected in an inverted funnel (Fig. 67) and tested chemically, the gas proves to be oxygen. All green plants liberate oxygen when growing in sunlight, a process that is exactly the reverse of the respiration of animals, which absorb oxygen gas and liberate carbon dioxid gas.

Photosynthesis is the foundation of all life, since the life of all animals as well as plants depends upon starch. Its relations to various external conditions are as follows: —

Chlorophyll.—Photosynthesis is dependent upon chlorophyll and hence occurs in green plants only. Moreover, in these plants, photosynthesis occurs only in those cells that contain chlorophyll, and thus chiefly in the palisade and mesophyll cells of the leaf, although it may take place in other cells if they contain chlorophyll.

Sunlight.—Photosynthesis is dependent upon sunlight and therefore never occurs in plants unless they are in the light. The vigor of the process is dependent also upon the intensity of the sunlight. It is most active in direct sunlight, less so in diffused daylight, and stops entirely when light is withdrawn.

Carbon Dioxid.—Photosynthesis is dependent upon the presence of carbon dioxid. Those plants which live in the air will always have plenty of carbon dioxid, since the air contains this gas. Water plants depend upon the gas dissolved in water. The dependence of photosynthesis upon carbon dioxid can be shown if a green water plant is placed in sunlight in ordinary water, when bubbles of gas (oxygen) arise from it, showing the presence of photosynthesis. If, however, this plant be placed in a dish of *boiled* water which has been cooled, the bubbles do not arise from its leaves, showing that photosynthesis does not occur. Boiling the water drives off the carbon dioxid dissolved in it, and the plant, having no carbon dioxid at its command, cannot carry on photosynthesis.

Temperature.—Photosynthesis is dependent upon temperature. Even though the sunlight be brilliant, if the temperature be below freezing photosynthesis cannot go on. It can, however, take place in temperatures very slightly above freezing, and will continue from this point up to moderately high temperatures. At higher temperatures, 120° to 130° F., the process stops. The temperature at which photosynthesis goes on most rapidly, the *optimum temperature,* varies with different plants, depending upon the structure of the plant itself. Some plants are so constructed that they can grow only at moderately low temperatures, and others only at high temperatures. In some of the arctic plants, photosynthesis, as well as all the other functions of the plant, goes on very readily when the temperature is not much above freezing, whereas in tropical plants photosynthesis does not occur unless the temperature is high.

METASTASIS

Photosynthesis may be spoken of as food *manufacture,* for the starch thus made is later utilized for the life processes of the plant. The *use* of this starch as food is generally spoken of under the term **metastasis** (Gr. *meta* = beyond + *histanai* = to place). This is too complicated a process to be described here in detail, and only a few of the main features will be briefly explained.

As already stated, the plants take in through their root hairs not only water but a number of ingredients dissolved in it Among these are nitrates, phosphates, potash, and various other substances in smaller quantities. All of these substances are carried up through the plant and distributed so that each living cell may receive some of this dissolved material. The starch, formed chiefly in the leaves, as we have seen is converted into sugar, chiefly in the night, and then transported through the plant in the sieve cells of the bark. The living cells in the various parts then take the water and minerals brought with the ascending sap, and the sugars brought from the leaves, and by changes

of complex but unknown nature cause them to combine within the cell protoplasm into new substances.

These new substances are of many varieties. The most important among them is the class of compounds which we have already learned to call **proteids.** Proteids contain chiefly the elements *carbon*, *oxygen*, *hydrogen*, and *nitrogen*, and are built out of the nitrates and other minerals absorbed from the soil, in combination with the sugars brought to them from the leaves. Proteids are not the only substances manufactured in the plant cells. Fats are produced which may be stored away in the plants or used for other purposes. Wood is also made and deposited around the protoplasm, forming the walls of the wood cells. Numerous other substances are produced which we need not mention, for the end result is the growth of all parts of the plant which increases in size as these new substances are formed. In all cases, however, the starch made by the leaves is the foundation of the new substances made. Starch is always used up and the plant can grow only so long as it has starch at hand in abundance. This process of using starch and making other substances is known as **metastasis.**

One of the results of the use of starch for any of these purposes is a combination of part of its carbon with oxygen, forming CO_2. This is a process similar to the respiration of animals, and the CO_2 is in plants, as in animals, a waste product which must be excreted. It is thus seen that plants carry on two opposite processes. By photosynthesis CO_2 is utilized, starch is formed and O is set free; by metastasis O is used, starch is destroyed and CO_2 is set free. During the ordinary life of a plant in daylight, although both processes are going on simultaneously, photosynthesis is much more vigorous than metastasis, and much more starch is made by the plant than is used, so that oxygen is constantly eliminated. Photosynthesis, since it takes place only in sunlight, can occur only in the daytime, while metastasis, requiring no sunlight, can go on in the night. The process of metastasis goes on fully as well, and certain phases go on better,

in the darkness than in the light. As a result, green plants in sunlight and in the daytime give off a surplus of oxygen, while in the night they are giving off carbon dioxid but no oxygen. Oxygen gas is a material that is utilized by animal life, while carbon dioxid gas is a waste product of animals as well as plants. Hence it has been said that, in the daytime plants are useful in a living room, while in the night-time they are harmful. There is really no foundation for this claim, since the amount of carbon dioxid given off by a few plants in a room is so slight that it is of no practical significance in its bearing upon animal life. In nature, however, the plant and animal life balance each other; while animals absorb the oxygen given off by plants, they themselves give off carbon dioxid that is utilized by plants; and thus the condition of the atmosphere is kept practically constant so far as concerns its content of both oxygen and carbon dioxid.

In general, plants manufacture far more starch than they need for their own life. The surplus is stored in some form as *starch*, *sugar*, *fat*, *proteid*, or some other material, and upon this surplus the whole animal world is nourished.

All ordinary green plants carry on this process of photosynthesis. Fungi, illustrated by *bacteria*, *yeasts*, *molds*, *mushrooms*, etc. (Figs. 32, 34, 42), all agree in lacking the green chlorophyll and are for this reason sometimes called colorless plants. Since they have no chlorophyll they are unable to carry on the process of photosynthesis, unable to utilize the energy of sunlight and manufacture starch. But they must have energy as well as green plants for their life, and are therefore dependent upon the latter for their food. The *Fungi* are commonly found growing and feeding upon organic foods, and are quite unable to utilize the minerals of the soil and the gases of the air. They are usually found, therefore, in the midst of masses of decaying organic refuse, on dead tree trunks, in manure heaps, growing from rotting leaves, etc. They feed upon the remains of past generations of green plants, having, as we shall see later, a very important part to play in nature's food cycle.

PHOTOSYNTHESIS AND METASTASIS CONTRASTED

The relation between these two functions of plant life may be better understood by the following contrast:—

PHOTOSYNTHESIS	METASTASIS
Takes place only in green cells.	Takes place in all living cells.
Takes place only in light.	Takes place equally well in darkness.
CO_2 is absorbed and used up and oxygen given off.	Oxygen is absorbed and used and CO_2 given off.
Carbohydrates are formed.	Carbohydrates are destroyed.
The plants grow in weight.	The plants lose weight, but may increase in size.
The energy of sunlight is stored; see Chapter XV.	The stored energy of sunlight is liberated and used.

The forces concerned in starch making and the building of proteids and other materials are ordinary chemical and physical forces. While we cannot cause these particular chemical combinations to occur in our laboratories, and do not understand them fully, we do know enough about them to prove that they belong to the ordinary forces of chemical affinity. In starch making the atoms are combined in ordinary proportions, and there is no reason for thinking that any other factors are concerned besides those of chemical affinity.

MISCELLANEOUS FUNCTIONS OF PLANT LIFE

Besides the processes of photosynthesis and metastasis, the only other prominent function of plant life is reproduction. The two functions of motion and coördination, which are very prominent in animal forms, are very slightly developed among plants.

Motion.— The most striking distinction ordinarily recognized between animals and plants is the absence of the power of motion in plants and its presence in animals. This distinction, however, is by no means a sharp one, for motion is not wholly lacking in plants. Many of the lower types of plants are capable of locomotion. This is confined largely to the microscopic forms, and in some plants it is present only in their reproductive spores. For example, *Ulothrix* (see page 93) is a motionless organism in its ordinary adult form, but produces reproductive spores, called *zoöspores,* which swim rapidly in the water. Among other microscopic plants, locomotive power is found even in the adult life of the animal. This is true of *Oscillaria, Diatoms,* and some other organisms; Fig. 68. Among the higher plants no active type of locomotion is found, although many of them are constructed in such a way that they may be carried to and fro by motile animals. Even among the highest plants, however, a certain amount of motion is developed in the different parts of the plant. Among the flowers of the highest groups of plants, motion is developed in certain parts of the flowers for the distribution of pollen. In most of the highest class also, careful study has shown that the leaves are constantly in a state of slow motion, waving to and fro during the growth of the plant in sunlight. Of course the leaves are almost always moved by the wind, but quite independently of air currents they have a motion of their own which can be detected by a careful recording apparatus. It is thought that this motion is due principally, perhaps entirely, to the unequal evaporation of water on different sides of the stem. At all events it is so slight that it can hardly be considered true motion, and it certainly

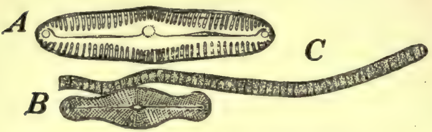

FIG. 68.—THREE PLANTS HAVING THE POWER OF MOTION

A and *B*, *Diatoms*, which move readily through water; *C*, *Oscillaria*, which simply waves back and forth.

is not locomotion. In addition to this, some plants have the peculiar property of closing their leaves in the night. The leaves droop and close themselves in such a way as to present a small surface for evaporation. This motion is sometimes spoken of as the *sleep* of plants. It is not developed in all, but it is more common than has generally been believed.

Thus, while it is believed that plants do not as a rule possess the power of motion and, except in the lowest forms, no power of locomotion, it is not absolutely true that motion is lacking in the vegetable kingdom. Speaking in general, however, plants are characterized by absence of motility.

Coördinating Functions.—Plants have nothing whatever that corresponds to a nervous system in the sense of possessing nerves or nerve fibers which coördinate the different parts of the body. There is practically no coördination between the functions carried on in the different parts of the plant. True *sensory functions* are also lacking from plants. In a general way the protoplasm of plants, as well as that of animals, is sensitive. All protoplasm reacts under certain stimuli and is therefore sensitive. Moreover, there are some of the higher plants which react so quickly and so strongly to certain stimuli that they are spoken of as *sensitive plants*. In the common so-called sensitive plant a touch upon the leaf will cause the leaf to close, and a slight touch of the branch will cause all the leaves on that branch to droop. Such a condition, however, is very unusual among plants, and in these cases it is incorrect to speak of the plants as sensitive in any proper sense. There is no reason for thinking that the plant has any sensation, *i.e.*, any true consciousness; and all that is meant by being sensitive in these cases is a quick ability to respond to an external stimulus.

CHAPTER VII

MULTICELLULAR ANIMALS: *HYDRA FUSCA*

GENERAL LIFE FUNCTIONS OF ANIMALS

THE life of animals is much more complicated than that of plants and the animal body is correspondingly more complex. It will make the study of multicellular animals more intelligible if at the outset we notice certain general functions of life that are exhibited by all higher animals. They are as follows: —

Alimentation (Lat. *alimentum* = food). — The process of food getting is called **alimentation.** The organs concerned in it are those that take food into the body, those that digest it, and finally those that absorb it into the circulating medium.

Circulation.—The process by which food and other ingredients are transported through the body is called **circulation.** Usually it is brought about by a circulating medium called the *blood*, by a series of tubes in which the blood is carried, known as *blood vessels*, and by a pump, or *heart*, designed to keep the blood in motion. In some of the smaller animals this system of organs is far simpler, neither blood vessels nor a heart being present; but some form of circulation is always found.

Respiration.—The chief chemical process in the animal body is *oxidation, i.e.*, the combination of the food with the oxygen. For this purpose, oxygen gas must be absorbed by the blood. As a result of the oxidation of the food another gas (CO_2) arises, which is also taken up by the blood and must be eliminated, since it is a waste product. The function by which these two gases (O and CO_2) are absorbed and discharged is called **respiration.** Respiration is thus *a gas exchange* that takes place between the body and the surrounding medium.

Metabolism (Gr. *meta* = beyond + *ballein* = to throw).—The foods taken into the body are eventually combined with the oxygen taken in by respiration and as a result new products

arise, some of which are useful, while others are waste products. The result of the combination of food with oxygen is, that a certain amount of force is liberated in the same way that heat is liberated from coal when it is burned. This force varies according to the amount of activity of the animal life. The whole process of chemical change by which the food is used is called **metabolism.** Two distinct phases of it may be recognized: **anabolism** (Gr. *ana* = up), the process by which complex substances are built out of simpler ones; and **katabolism** (Gr. *kata* = down), the process by which complex substances are torn down into simpler ones. In animals the latter are more extensive than the former.

Excretion.—The function of getting rid of the waste products of metabolism is called **excretion.** These products are no longer valuable but act as a direct poison to the body if allowed to remain. These waste products are solid, liquid, or gaseous. The gases are excreted by respiration, as just described. In higher animals the liquids are carried off by the *lungs*, by the *skin*, and by special organs called *kidneys*. It must be remembered that excretion does not refer to the passage from the intestines of the undigested food. This undigested food has never become part of the body and its passage from the intestines is not strictly excretion. There is apt to be confusion in the use of the terms, as the undigested food which passes through the intestines frequently goes by the name of *excreta*. In the strict sense, however, the excreta or fæces are not excretions.

Motion.—Practically all animals possess some power of **motion** and have special organs adapted for bringing it about.

Support.—The living parts of an animal (protoplasm) are made up of a soft, jelly-like substance, too non-resistant to have the power to hold any particular shape. If the animal is small the resisting power of the jelly may be sufficient to preserve its shape; but in large animals it is necessary to have some hard **support** for holding the soft parts. This hard supporting substance may be in the form of a *skeleton* or *shell*.

Coördination.—The numerous activities of the animal body are brought into harmonious action for a common purpose. The function by which they are related to one another is known as **coördination** (Lat. *con* = together + *ordinare* = to regulate), and the system of organs that produces this coördination is generally spoken of under the name of the *nervous system*.

Reproduction.—This is the function of producing new individuals like the old, which prevents the species from disappearing from the earth.

The nine functions thus outlined are necessary to the life of all animals. In a few of the lower animals, some of these functions are very slightly developed; and in quite a number of smaller animals we do not find any special system of organs devoted to some of these functions. For example, many small animals have no skeleton, and some of the very simple ones have no organs that can properly be called a coördinating system, since all of the functions of the animal take place in one small cell where no coördination is needed. But speaking in general, all animals, high or low, carry on all these functions.

ANIMAL BIOLOGY

In our consideration of animal Biology we shall study three animals, chosen to illustrate different grades of structure. *Hydra* will be an example of one of the simplest multicellular animals; the earthworm, an animal of moderate complexity; and the frog will be an example of the more highly complex types.

HYDRA FUSCA: A SIMPLE MULTICELLULAR ANIMAL

General Description.—The brown *Hydra* is a very common water animal and may be found in almost any pond on the under side of lily pads or pond weeds. Here it may be seen as a small reddish body, just large enough to be visible. Our common *Hydra* (*Hydra fusca*) is of a brown color, but another common species (*Hydra viridis*) is bright green. If the animal, still

attached to the lily leaf, be removed from the pond, placed in a dish of water and left undisturbed for a time, it will slowly expand and assume the form represented in Figure 69 *A*. It shows then a slender body about a quarter of an inch or less in length, attached at one end to some other solid object. At the other end it bears a crown of **tentacles,** which in the brown *Hydra* are from five to ten in number, and in the green *Hydra* are from five to twelve. These tentacles are very delicate, hairlike bodies, which may be expanded to considerable length, as at *A*, but when contracted, shrink into minute knobs hardly big enough to be seen. Indeed, the whole body of the *Hydra* is extremely contractile, and though when undisturbed it may be a half an inch or more in length, on being disturbed it will contract into a small body no larger than a pinhead; see Fig. 69 *B*. *Hydra* seems at first to be a stationary animal, although it can move its tentacles slowly to and fro in the water. A careful examination, however, shows that it has some power of motion; the animal, creeping by means of its base, can move slowly over the object upon which it is fastened. Occasionally also it moves by turning end over end. It first attaches its tentacles to the object to which its base is attached. Then the base lets go its hold and is moved over and fastened again in another spot. The tentacles let go their hold and the animal straightens up. The movement is not unlike that of a boy turning a handspring.

Structure.— In the midst of the crown of tentacles is a little conical projection, on the top of which is a mouth. This is star-shaped rather than circular, and opens into a cavity which fills the whole of the body of the *Hydra* and even extends into its tentacles. This cavity is the digestive cavity and is called the **gastrovascular cavity;** see Fig. *C*.

Hydra is a true multicellular animal, made up of many thousands of cells which are not alike but show a considerable differentiation and have a division of labor among them. All of these cells, however, are arranged into two layers, one on the outside called the **ectoderm** (Gr. *ectos* = outside + *derma* = skin), *ec*

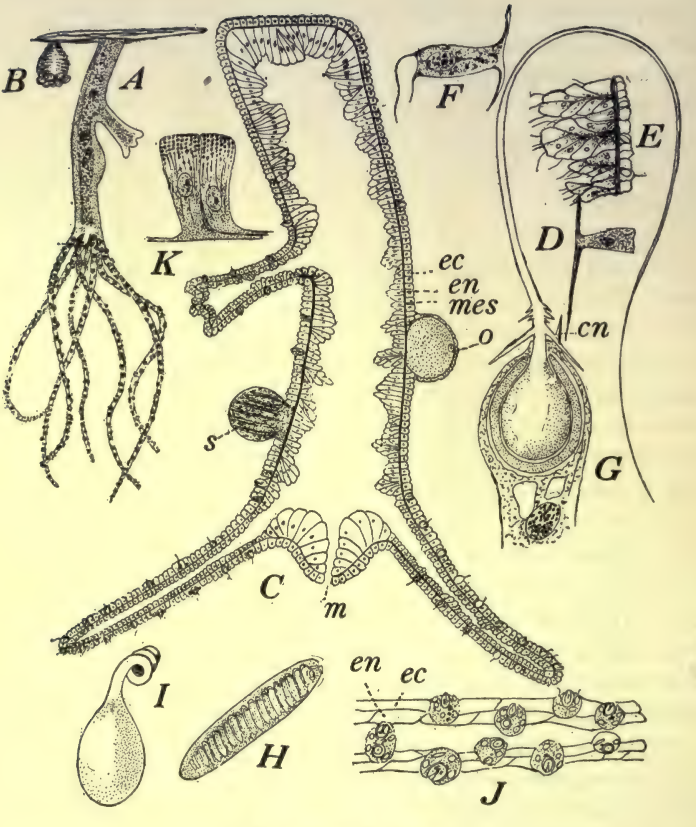

FIG. 69.— *HYDRA*

A, an animal in its expanded form; *B*, the same animal contracted; *C*, a diagram of the longitudinal section of the animal, showing the internal structure; *D*, an epithelio-muscle cell; *E*, a bit of the body wall highly magnified showing the two layers of the body; *F*, a digestive cell; *G*, one of the nematocysts with its thread extruded; *H*, a second type of nematocyst with the coiled thread within the sac; *I*, nematocyst of the third type with its thread extruded; *J*, a bit of the tentacle, very highly magnified, showing the batteries of the nematocysts; *K*, two of the secreting cells of the basal disk.

cn, cnidocil; *ec*, ectoderm; *en*, endoderm; *m*, mouth; *mes*, mesoglœa; *o*, ovary; *s*, spermary.

(Fig. *C*), and one on the inside called the **endoderm** (Gr. *endon* = inside), *en.* These two layers are found throughout the body, both the ectoderm and endoderm extending into the tentacles to their very tips. *Hydra* is thus a double sac with no space between its two layers. The layers of ectoderm and endoderm are not in actual contact with each other, but are separated by a thin supporting layer known as a **mesoglœa** (Gr. *mesos* = middle + *gloia* = glue), *mes.* By means of this intermediate layer, the ectoderm and endoderm are very firmly attached to form one solid mass, forming a **body wall** made up of two layers of cells.

Ectoderm.—The ectoderm is made of two chief kinds of cells. The first of these is the **epithelio-muscle cells**; Fig. *D.* These are in the shape of cones, with their broad ends outward and their tapering ends toward the mesoglœa. At the tapering ends some long fibers protrude which extend over the body of the animal next to the mesoglœa. The great contractility of *Hydra* is due to these fibers. The second type of cells is the **interstitial** (Lat. *inter* = between + *sistere* = to stand) **cells.** These are found between the first cells and are somewhat smaller than the epithelio-muscle cells. They are chiefly interesting because they produce a very peculiar type of organ possessed by *Hydra* known as the **nematocysts** (Gr. *nema* = thread + *cystis* = sac). The nematocysts, or **stinging cells,** are little sacs scattered all over the outside of the body of the animal, especially in the tentacles. Each of these is an oval sac, one side of which is pushed inward like the finger of a glove inverted into its palm; Figs. *G*, *H*, and *I*. This inverted portion is in the form of a long thread, much longer than the diameter of the sac, and is wound up in a long coil inside of it; Fig. *H*. Besides this thread the sac contains a liquid. The peculiarity of these cells is that under a proper stimulus the minute thread may be inverted from the sac as shown in Figure *G*. This inverted portion when discharged carries with it a small quantity of poison, and thus each thread serves as a little poison dart. The thread

is not shot away from the animal, but only protruded to its length. If any small animal with thin skin comes in contact with the *Hydra*, some of these threads are discharged, the animal is hit by them, paralyzed by the poison, and then transferred to the *Hydra's* mouth by means of its tentacles. In *Hydra* these cells are so small that they cannot pierce the human skin and their sting cannot be felt; in some allied animals, like the *jellyfishes* or *sea nettles*, these cells, although the same in structure as those of the *Hydra*, are much larger and may produce a severe sting. After the thread is once discharged, it cannot be withdrawn again into its sac; the cell thus becomes useless. It is necessary, therefore, for *Hydra* to be constantly replacing them, and new nematocysts are constantly growing from the old interstitial cells. The special cell that produces the nematocyst is known as the cnidoblast. This is simply one of the interstitial cells which has for its function the production of these stinging sacs.

In the brown *Hydra* there are three kinds of nematocysts. The larger one, *G*, is somewhat pear-shaped, and when its thread is protruded it has, close to the base of the thread, two or three slender barbs projecting backwards. When the thread is discharged from the cell these barbs are ejected first. It is thought that their function is to pierce the skin of the animal into which the poison is to be ejected. Close to the base of the thread is a minute little organ called the **cnidocil** (Gr. *cnidê* = thistle) whose function is unknown; Fig. *G*, *cn*. It has been supposed that it helps to discharge the cell as a trigger does a gun. This is doubtful, for it is known that the cell is most easily discharged by changing the internal pressure, rather than by any mechanical touch upon this cnidocil. The second of the nematocysts in the *Hydra*, *H*, is smaller but more elongated. The thread when discharged is very different in shape, lacks the projecting barb, and, relative to the size of the sac, is much longer. The third cell is smaller still, *I*, oval in shape, and contains a thread that when discharged always coils up in a spiral form. It is thought

that this spiral coiling is to enable the animal to adhere to the minute spines or hairs of its prey by coiling around them in a corkscrew fashion.

The nematocysts are scattered all over the body of *Hydra* except in its base. In some parts, especially in the tentacles, they are grouped into little bunches which project from the side and form tubercles; Fig. *J*. These little clusters are spoken of as **batteries.**

The Basal Disk.—The base of *Hydra* is different from the rest of the body. It secretes a sticky substance by means of which the animal attaches itself to an object. This base has the power of causing the animal to glide very slowly over the object upon which it is attached, though the exact method by which this motion is produced is not known. In this part of the body the nematocysts are lacking, and the epithelio-muscle cells not only have muscle fibers but some of them have the function of secreting a cement, and differ in appearance from those of the rest of the body; Fig. *K*.

Endoderm.—The endoderm is about twice as thick as the ectoderm and contains cells of two kinds, known as the **digestive cells** and the **secretory cells.** The *digestive cells* are long and cup-shaped, and have, extending from their base next to the mesoglœa, fibers of contractile substance. At their inner or free end they bear two lashing *flagella;* Fig. *F*. It is interesting to note that the free end of these cells may be protruded in the form of pseudopodia, much like those already seen in the *Amœba,* and that they are able to take into their bodies small solid particles of food which are then probably digested within the cells of the body itself. Thus *Hydra* has a function of digestion similar to that of the *Amœba,* being able, to a certain extent, to take inside of its digesting cells solid particles of food and to digest them (*intracellular digestion*). The chief digestion, however, is carried on by the other cells, the *secretory cells.* These are smaller than the digestive cells and lack the contractile fibers at their base. They produce a secretion which is discharged

from their free surface into the cavity of the body, and is thus poured upon the food which is taken into the mouth and lies free in the gastrovascular cavity (*intercellular digestion*).

Hydra has thus, in addition to a method of digestion which resembles that of the *Amœba*, the power of producing a digestive secretion, which is poured upon the food in the general cavity, only the nutritious portions of the food being absorbed after digestion. This method of digestion, which is peculiar to the higher animals, is, in the *Hydra*, combined with the simple method of digestion characteristic of the *PROTOZOA;* and in this respect the *Hydra* represents a transition stage between the unicellular animals and the higher, multicellular forms. The function of the hairlike flagella on the endodermal cells apparently is to keep in circulation the liquids present in the body and thus to aid in bringing the digestive juices in contact with the food which lies in the cavity. This is the only trace of a circulatory system that the *Hydra* possesses.

Nervous System.—According to recent investigation, it seems that *Hydra* possesses a very simple **nervous system,** so delicate, however, that it requires special methods of study; and very little is known about it. There is a series of nerve cells near the mouth and another near the base of the animal, and these are connected with excessively delicate fibers passing over the body. There are sensory cells on the surface layer that are probably connected with the nerve cells, and some of the nerve cells apparently send nerve fibers to the contractile fibers of the epithelio-muscle cells. This system is, however, very simple and rudimentary, and is of interest chiefly as the simplest type of nervous system found among animals.

Growth and Budding.—The food of *Hydra* consists mainly of minute water animals which are captured by means of its tentacles. The tentacles are protruded into water, and small animals, coming in contact with them, are paralyzed by the discharge of the nematocysts. The tentacles then transfer the food to the mouth. It is pushed into the gastrovascular cavity

and then, by the contraction of the body wall, forced downward to the basal end of the cavity. Here it is mixed with the digestive juices of the animals and slowly digested. In time the digestive parts are dissolved and absorbed into the cells that form the body wall and are assimilated. After all the nutritious portions have been digested and absorbed from the food particles, the undigested refuse is then ejected from the mouth by a sudden contraction of the body and opening of the mouth, which throws the ejected portions some distance from the animal. As the result of digestion and assimilation, the animal grows.

After it reaches a certain size, rarely more than one-half an inch in length, the further growth shows itself in the formation of buds which appear on the sides of the old individual; see Fig. *A*. These buds rapidly increase in length, and after a time a circle of minute secondary buds can be seen at their tips. These secondary buds are rudimentary tentacles, for they increase in length till eventually they become new tentacles. In the middle of the circle of tentacles thus formed a small opening makes its appearance, which forms a new mouth at the end of the growing bud. After a time the bud itself separates from the body of the animal from which it grew and floats off by itself as an independent individual, identical in structure with the one from which it came, though somewhat smaller. In this way the *Hydra* reproduces itself indefinitely by budding (*gemmation*) as long as it has sufficient food and proper conditions for feeding and growth. If the conditions are favorable two or more buds may be seen arising from the same individual, and occasionally a secondary bud may be found arising from the side of the bud, even before it has broken away from the animal that produced it. In the case of the *Hydra*, however, these buds do not remain attached very long, but always separate; so that we never find the animals grouped together in great masses. While we may find one *Hydra* with one, two, or three buds, this is the extent of group formation. In closely allied animals, however, the budding may go on almost indefinitely, and groups are formed

containing hundreds of members, all having arisen from the original by budding. This occurs among the hydroids which are common at the seashore, examples of which are shown in Figures 70, 72, and 73. In such colonies the individual members are called **zooids.**

Polymorphism.—In the colonies of hydroids shown in Figure 71 the members of the colony are all alike. It not infrequently happens, however, that when one of these hydroids produces a colony by budding, the members (*zooids*) assume

FIG. 70.—*PARYPHA*

An animal related to *Hydra*, but forming colonies by budding.

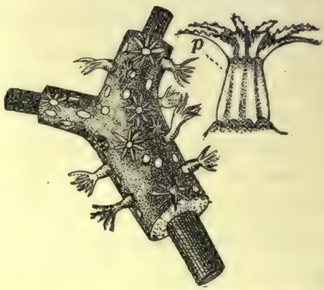

FIG. 71.—*ALCYONIUM.* AN ANIMAL RELATED TO *HYDRA* WHICH FORMS COLONIES

The individual members, which have arisen by budding, are imbedded in a lime base; *p*, one of the members of the colony more highly magnified.

forms unlike each other. In Figure 72 will be seen a colony with two types of members; one of them possessing tentacles and adapted for feeding, and the other without tentacles but developing the reproductive bodies inside of a case. One of these members is known as the *nutritive zooid, nz,* and the other as the *generative zooid, gz.* In some other types of hydroids the members which arise by budding assume even a greater variety of form. In the colony shown in Figure 73 there is a complicated

colony made up of at least five different types of members or zooids. Among them may be found members adapted to feeding, *n;* others having purely sensory functions, called *tentacular zooids, t;* some adapted for reproduction, *g;* others in the form of bells with muscles which enable them to move about, called the *swimming zooids, sw;* and finally at the top of the colony

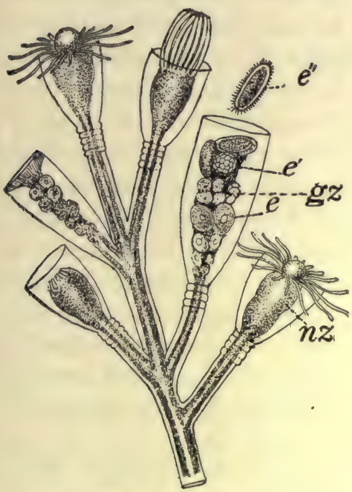

FIG. 72.—*CAMPANULARIA*

A colony of Hydroids showing a differentiation into feeding zooids, *nz*, and generative zooids, *gz; é, e,* eggs in different stages of development; *é″* the young embryo extruded into the water.

FIG. 73.—A SIPHONOPHORE

An animal showing a high condition of polymorphism; *f*, the floating zooid; *g*, the generative zooid; *n*. the nutritive zooid; *sw*, the swimming zooid; *t*, the tentacular zooid.

a single one develops as a gas bladder, *f*, which enables the animal to float in the water. All of these combine to form a colony. Where several different types are found arising by budding from the same original stock the condition is spoken of as **polymorphism** (Gr. *polus* = many + *morphé* = form). Polymorphism is best illustrated in simple organisms, being well developed among the animals related to the *Hydra;* but the same

principle is found in a less developed extent in some of the organisms with a higher structure, though nowhere do we find it so highly developed as among the hydroids. Where polymorphism is developed the whole colony acts as a unit, and the colony, therefore, may be compared to a more highly complex organism with its various organs. Polymorphism always arises as the result of asexual growth and not by sexual reproduction, and when it occurs the members of the colony always show a differentiation in function as well as in shape and structure.

Regeneration of Lost Parts.—*Hydra* has a wonderful power of reproducing lost parts. If it is cut into two pieces, each part will develop the part that it has lost and becomes a new *Hydra*. Indeed, it may be cut into a large number of fragments, and every fragment is capable of growing and developing into a new form like that of which it was originally a part. If the small conical projection containing the tentacles is cut off from the rest of the *Hydra*, each piece will develop the part that it has lost. The animal may be split lengthwise into two or four parts and each will become a perfect animal. If a head is split in two and the parts slightly separated, each will develop its crown of tentacles and a two-headed animal will result. If an animal is turned wrong side out, it will adjust itself to new conditions and a perfect animal will soon be produced. This power of regenerating lost parts is found in many of the lower animals, but in no place is it better developed than in *Hydra*. In the higher animal the power of regenerating lost parts eventually disappears entirely. It is very evident that this power must be of considerable advantage to the animal in the struggle for existence. In *Hydra* the power is so extraordinarily developed that a piece of the animal not more than one-hundredth of an inch in length is capable of reproducing all of the parts that are lacking and developing into a new animal. In some cases the new animal is produced by a multiplication of cells from these pieces, so that a fair-sized animal is developed; while in other cases the cells and fragments are remolded into new individuals

which are like the original in shape but much smaller in size. Some of the experiments described were originally performed long ago, by Trembley in 1740; but they have since been confirmed by other investigators.

Sexual Reproduction.—By the method of budding *Hydra* may multiply indefinitely as long as it has plenty of food. It has also a second method of reproduction by a true sexual process. Under certain, not well-understood, conditions the animal produces outgrowths on its side, shown in Figure 69 *C*, which are the sexual glands,— **ovaries,** *o*, and **spermaries,** *s*. Within them are produced special cells, called **eggs** and **sperms,** which unite with each other in a manner similar to that seen in the cells of *Pandorina* (page 74). The significance of this reproduction will be noticed in a later chapter.

Hydra, as will be seen from the above description, possesses the systems of *alimentation*, *metabolism*, *motion*, and *reproduction*. *Circulation* is wanting; *respiration* is carried on through the general surface of the cells; no *excretory system* is found, each cell probably excreting its waste products directly into the water; *support* is unnecessary in such a small animal; the rudiments of *nerves* suggest the beginning of a *coördinating system*.

THE RELATION OF THE WHOLE ORGANISM TO ITS DIFFERENT PARTS

With the appearance of multicellular organisms we also find that the entire animal has now a life more or less independent of the life of its parts. The multicellular animal or plant lives a life as a complex, and in addition each cell has a life of its own; so that we can distinguish, in a multicellular animal, a life of the organism as a whole and a life of its separate cells. It is possible for the death of the organism as a complex to occur while the individual cells still remain alive. It is true that in the multicellular organism each of the individual cells is dependent upon the activity of the whole to keep it properly nourished and supplied with the necessary conditions of its life. The different

cells that make up such organisms are not independent and cannot live long except when related to the other cells that make up the multicellular organism. Nevertheless, there is a certain amount of independence in the individual cells, especially among plants and some of the lowest animals; for in these we may remove only a comparatively small number of cells from the whole organism and these cells will still retain their vitality, still continue their power of growth, and under proper circumstances develop more cells which eventually become exactly like the animal from which they were obtained. This is especially true of *Hydra*, which can be cut into many pieces, each piece retaining the power of independent life, and in time becoming an independent and well-developed animal. In such low organisms the life of the organism as a complex has not wholly destroyed the independence of the individual parts. This is more or less true throughout the whole of the plant kingdom. Among most higher plants as well as the lower, small pieces separated from the parent plant will not die at once, but may, if put under proper conditions, develop into fully grown individuals like those from which the fragments were obtained.

With animals, however, it is only among the lowest and simplest forms that a piece, containing a relatively small number of cells, can be separated from the rest and still be capable of developing into a new organism like the original, as in the case of the *Hydra*. As we pass to the higher animals this power of regeneration disappears, and among almost all animals, even of comparatively low structure, the independent life of the parts is lost, so that when one portion is removed from the complex that makes up the animal it no longer retains its power of life and growth. But even in these cases and among the highest animals, we do find that some parts may have more or less independent life when separated from the organism of which they are a part. In an animal like a frog, for example, the heart may be totally removed from the body and it will still keep up its life for many hours when put under proper condi-

tions, long after the frog itself has been killed. More remarkable is this power in the case of a turtle, for here even when the animal has its head entirely cut from the body, and the rest of the animal destroyed, the heart, if removed and kept under proper conditions, will keep on beating for at least two days. Still more remarkable is it to find that in the air passages of the turtle there are ciliated cells which have a special power of motion; Fig. 14 *C*. During all the life of the turtle these cilia are in a state of active motion, and after the turtle is dead the cilia may continue moving for as long as two weeks. We thus see that among the higher organisms the death of the animal as a whole does not necessarily involve an immediate death of all its parts. The individual parts are, of course, closely dependent upon each other, and, at least in the higher organisms, the life of neither is capable of being long maintained without the other; but the life of the individual cell may frequently continue some time after the life of the organism as a whole has been brought to an end.

From this it follows that the term **death** may have a different meaning in different connections. In speaking of the death of an animal, we may refer, and usually do refer, to the death of the animal as a whole, which means the destruction of the complicated mechanism that forms the animal organism. But we may also refer to the death of the individual parts, and in this case the exact time when the animal comes to its death is difficult to state. The animal as a whole may die on one day, while some of its parts may remain alive at least two weeks. In such instances it is not easy to say when death occurs. Nevertheless, it is customary to refer by this term, not to the death of the individual parts or the individual cells which make up the animal, but to the destruction of the organism as a whole, which causes it to cease to act as a unit. Usually, therefore, death refers to the breaking down of the *mechanism* of which an organism is composed so that its parts do not act together.

LABORATORY WORK

Hydra.—Almost any pond will furnish *Hydra*, which may be found clinging to the under side of pond-lily leaves. If such leaves are placed in a dish of clean water, the *Hydra* will detach themselves from the leaves and cling to the side of the dish. For study, a specimen is to be detached from the dish, placed in a watch glass containing a little water, and examined under the microscope with a low-power objective. The general structure and motion of the animals may easily be seen. For the cellular structure of the body, stained, mounted sections should be furnished the student by the instructor. For a study of the nematocysts, a bit of the tentacles of a brown *Hydra* should be cut off with delicate scissors and placed on a slide in a small drop of water. A cover glass is placed upon the drop and gently pressed. This will crush the tentacle and cause many of the nematocysts to discharge their stinging hairs. The nematocysts may also be made to discharge their stinging hairs if a little weak acetic acid is added to the water. A careful examination with a $\frac{1}{6}$-inch objective will show all three kinds of nematocysts, both discharged and undischarged. For comparison of *Hydra* with other *Hydroids*, preserved and mounted specimens should be furnished by the instructor, some of which should show colonies and others jellyfishes.

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CHAPTER VIII

MULTICELLULAR ANIMALS: THE EARTHWORM (LUMBRICUS)

The earthworm is an extremely common animal the world over, being found buried in moist earth in practically all parts of the world. There are numerous species, differing from each other in minor details, but agreeing in their fundamental structure. The animals vary in size from those an inch or two in length, to some which are nearly a foot; and one species is reported two feet in length. Earthworms are of practical importance in stirring up the soil. They are constantly engaged in bringing soil from below to the surface, and depositing it at the mouths of their burrows. By this slow but constant action they are of much value to agriculture, constantly renewing the surface soil.

ANATOMY

Shape of Body.—Examined externally, the earthworm is an elongated animal, more or less cylindrical in shape, tapering, however, at the two ends; Fig. 74. The head, or **anterior end,** is more tapering than the other, the blunter one being the **posterior end.** One side of the animal is lighter colored than the other and slightly flattened, the opposite side being more rounded. When the animal is in its natural position on the surface of the ground, the flat side is kept undermost and the rounded and darker-colored side uppermost. We thus have an anterior and a posterior end, a **ventral** and a **dorsal** surface, and, consequently, a **right** and **left** side to the animals. The animal is, therefore, **bilaterally symmetrical.**

Segments or Metameres.—The body of the earthworm is divided into a number of rings (Fig. 74) called **segments** or **metameres** (Gr. *meta* = after + *meros* = part). The number is not constant, being greater in the older and larger animals

than in the younger ones, and increasing with age. Most of these rings are alike in shape and size, but a few of them differ slightly from the others. The first one at the anterior end is not a complete ring, but a minute projection which is known as the **prostomium** (Gr. *pro* = before + *stoma* = mouth). It is slightly movable and is the most sensitive part of the animal. The second segment is not a complete ring, but rather in the form of a horseshoe, with the open part of the horseshoe above, and with the prostomium lobe fitting into the openingas shown in Figure 75.

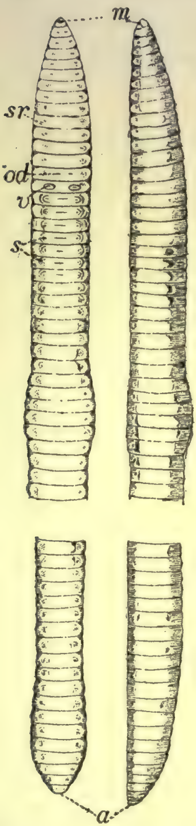

FIG. 74.—AN EARTHWORM, FROM BELOW AND FROM THE SIDE

a, the anus; *m*, mouth; *od*, opening of oviduct; *sr*, opening of seminal receptacles; *v*, opening of vas deferens; *s*, setæ.

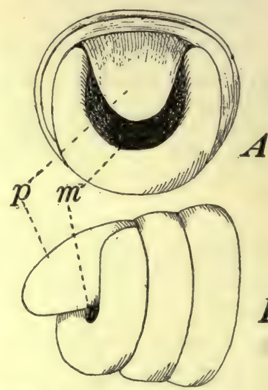

FIG. 75.—THE FIRST THREE SEGMENTS OF THE EARTHWORM

A, from the front; *B*, from the side; *p*, the prostomial lobe; *m*, the mouth.

Underneath the prostomium and over the second segment is an opening, the **mouth,** *m*. The third segment is a complete ring, but rather small, and from this point backwards the segments are all alike in shape, increasing slightly in size until a maximum is reached, and from this point remaining essentially the same in size and shape to the posterior end of the body. A short distance back from the head there is a series of rings, from the twenty-eighth

to the thirty-fifth segments, known as the **clitellum** (Lat. *clitellæ* = saddle); Fig. 74. These segments are larger than elsewhere and have a thicker wall and special functions. At the extreme posterior end the segments become smaller, and the last one has an opening which is the posterior opening of the digestive tract, the **vent** or **anus,** *a.* Because of this ringed structure the earthworm belongs to a class of animals called *Annulata* (Gr. *annulus* = ring).

Structure of the Body.—The body of the earthworm can be compared to a tube within a tube; Fig. 76. The outer tube is called the **body wall,** *b*, and the inner tube the **alimentary canal** or the **digestive tract.** Between the body wall and the digestive system is a space filled with a liquid, this space being a true **body cavity** or **cœlom** (Gr. *koilos* = hollow), *c*, differing thus from *Hydra*, that has no cœlom. The body cavity is not, however, an open space extending from the anterior to the posterior end, but is divided by partitions into a series of chambers, with a chamber for each segment. The partitions are called **septa** (sometimes called *dissepiments*). There are minute openings through each septum, so that the liquid that fills the body cavity may pass through; thus the different chambers are in communication with each other.

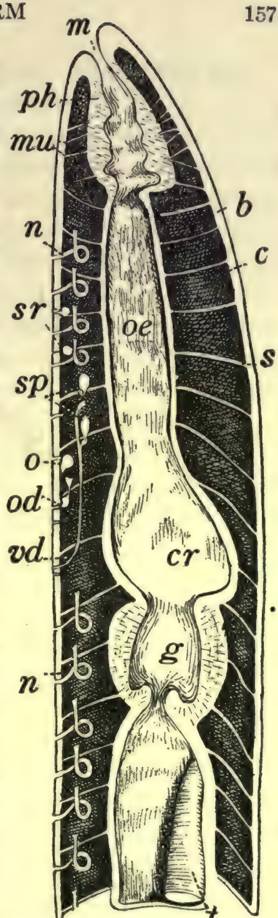

Fig. 76.—Diagram showing the anterior end of the earthworm cut lengthwise through a vertical median line

b, body wall; *c*, cœlom; *cr*, crop; *g*, gizzard; *m*, mouth; *mu*, muscles; *n*, nephridia; *o*, ovary; *od*, oviduct; *oe*, œsophagus; *ph*, pharynx; *s*, septa; *sp*, spermary; *sr*, seminal receptacles; *t*, typhlosole.

The Alimentary Canal.—The alimentary canal (*enteron*) is a straight tube extending from one end of the animal to the other, without any convolutions. It does, however, show several distinct regions. The mouth opens into a slightly swollen section known as the throat or **pharynx,** *ph.* The pharyngeal walls are muscular, with a radiating series of muscles that pass outward to be attached to the body wall, *mu.* The contraction of these muscles will cause an expansion of the pharynx and convert it into a sucking organ by means of which the animal draws food into its mouth. Behind the pharynx the canal contracts into a straight **gullet** or **œsophagus,** *oe,* which continues back to the fifteenth segment. Here it enlarges into a thin-walled **crop,** *cr,* which is followed in the fifteenth and seventeenth segments by a second enlargement with thicker walls, called the **gizzard,** *g.* Beyond this the intestine extends in a straight line to the **anal aperture** or **vent.** The intestine is not a simple cylindrical tube but has its dorsal side folded inward to form a longitudinal ridge known as the **typhlosole** (Gr. *typhlos* = blind + *solen* = tube), *ty* (Fig. 81), whose purpose seems to be only to increase the amount of interior surface within the intestine.

Circulatory System.—The circulatory system consists of two parts, the *blood system* and the *cœlomic fluid.*

The blood system.—A series of tubes or vessels containing blood comprises the circulatory system. The blood of the earthworm is red, a very unusual condition among lower animals. The red color is due to a substance called **hæmoglobin** (Gr. *haima* = blood + Lat. *globus* = globe), which is dissolved in the liquid part of the blood, and is not contained in the corpuscles, as it is in the frog and higher animals. This blood is kept in constant motion in the vessels, forced along by their contractions. The chief vessels and the direction of the blood current are shown in Figure 77 and they are as follows:—

Running anteroposteriorly, just above the alimentary tract, is a large longitudinal **dorsal vessel,** *dv,* with muscular walls.

These muscles produce waves of contraction, which, arising at the posterior end, force the blood forward. In the posterior half of the body small branches pass from this tube into the intestine, *ei*, supplying its walls, and the blood then enters a rather large vessel in the typhlosole, from which it passes back by short tubes, *ai*, into the dorsal vessel. The greater part of the blood in the dorsal vessel flows forward to the segments 6–11, where five large circular vessels arise from it, *ht*, which pass around the sides of the body to enter a **sub-intestinal vessel,** *vv*, also extending lengthwise and lying beneath the intestine. These circular vessels are called **hearts,** since they contract, and force the blood downward into the ventral vessel. When reaching the ventral vessel, part of the blood flows forward, in front of the hearts, and part of it backward. From this ventral vessel branches arise which pass out into the body wall and into other organs supplying the body generally with blood. After passing through the organs of the body wall, etc., the blood is collected into another set of vessels which pass into a third longitudinal vessel lying under the nerve chord, the **subneural** (Gr. *neuron* = nerve), *snv*. Through this it flows toward the posterior end. In the intestinal region there arises from the subneural vessel, in each segment, a **circular vessel,** *cv*, which passes up around the body to empty

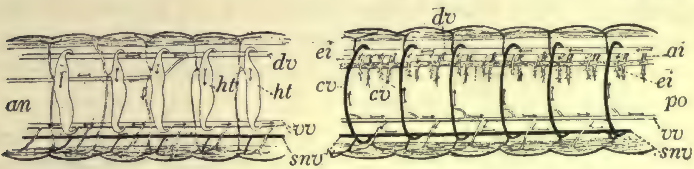

FIG. 77.—DIAGRAM SHOWING THE CHIEF BLOOD VESSELS OF THE EARTHWORM

an, the anterior end;
po, the posterior end of the body;
dv, dorsal vessels;
cv, circular vessels;
ei, efferent intestinal;
ai, afferent intestinal;
ht, hearts;
snv, subneural vessel;
vv, ventral vessel.

(Bourne and Benham.)

into the dorsal vessel, *dv*, thus bringing the blood back again into the dorsal vessel. There are numerous other small vessels, some of which are shown in Figure 77, but the chief ones are those that have been described.

The blood is forced onward by the contraction of the walls of the dorsal vessel and the hearts, which are provided with valves preventing any back flow when the contractions occur. The course of the blood is rather indefinite and the pure and impure blood are not distinctly separated from each other, as in higher animals. There are no true arteries or veins, and no true hearts. This blood is associated with respiration, and also carries nourishment from the absorbing organs in the intestine to the active tissues, and carries waste products from the active cells to the excreting organs.

Cœlomic or Perivisceral Fluid.—The chambers of the body cavity are filled with a fluid called the **cœlomic** or **perivisceral** (Gr. *peri* = around + Lat. *viscera* = internal organs) **fluid,** which serves also as a circulatory medium. The food that is absorbed makes its way into the body cavity and is partly absorbed by this fluid. This liquid is forced irregularly backward and forward through the cavity of the body by the motions of the animal, and the nutritious parts of the food which are dissolved in it are thus directly carried to and fro and brought in contact with the living tissues of the body, that are bathed in this liquid. There is no distinct circulation of this fluid, and it cannot properly be called a circulatory fluid. It does, however, have some of the functions of the blood, since it carries to and fro a part of the material absorbed from the digestive tract. It corresponds more closely to the lymph of higher animals.

Respiration.—The earthworm has no distinct respiratory system, but the blood vessels in their circulation in the skin are brought into a very close proximity with the air. Gases are readily exchanged through the thin skin, and respiration is carried on easily without any special respiratory organs except the minute blood vessels that lie beneath the skin.

Excretory System.—Most of the excreted matter (with the exception of gases) is passed to the exterior by a series of tubes known as **nephridia** (Gr. *nephros* = kidney), one pair in each segment. Each of them (see Fig. 78) consists of a long tube, which begins in a segment of the body cavity as a minute funnel-shaped opening, *i*, and then passes through the septa, *s*, to the segment immediately behind. In the posterior segment, the tube is coiled back and forth in three distinct loops that differ in structure and function. Eventually the distal end passes through the walls of the body to the exterior, by a lateral opening, *e*, in each segment. These nephridia are very delicate organs and can only be made out by very careful study with a magnifying glass. Their function in excretion is as follows: The funnel opening in the anterior segment is guarded with cells provided with cilia, and some of the coils are also lined with cilia.

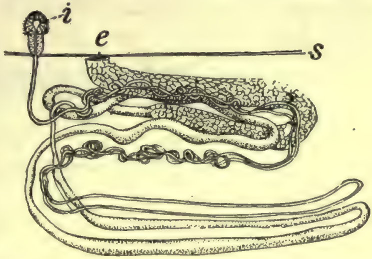

FIG. 78.—A *Nephridium*, complete

i, incurrent opening;
e, excurrent opening;
s, septa.

The movements of these cilia produce currents in the liquid in the tube and force the liquids through the tube to the exterior. As a further result of the action of these cilia, solid particles of waste material, which may be floating in the cœlomic fluid, are forced into the tube and then through the tube, passing through its coils and finally reaching the exterior through its opening. The coiled walls of the tube are made up of thick active cells which are well supplied with blood vessels. These are **secreting cells** and resemble **gland cells.** They have the power of extracting waste products from the blood and excreting them into the tube which they surround. The materials enter the duct of this nephridium and are slowly forced along by the ciliary current, and finally carried to the

exterior. These nephridia have as their primary function the removing from the body of the waste products containing nitrogen, related to **urea.** Their function is thus similar to that of the kidneys of the higher animals, and indeed their structure is not unlike the kidneys of some of the vertebrates.

The Coördinating or Nervous System.—The nervous system consists of a *central system* and a *peripheral* (Gr. *peri* = around

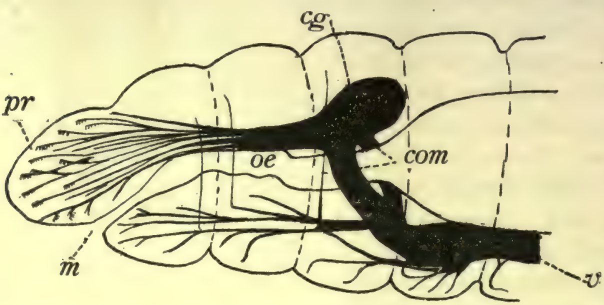

FIG. 79.—DIAGRAM SHOWING THE NERVOUS SYSTEM IN THE FRONT END OF THE BODY

cg, cerebral ganglia; *com*, commissures; *m*, mouth; *oe*, œsophagus; *pr*, prostomium; *v*, ventral cord.

(Shipley and MacBride.)

+ *pherein* = to bear) *system*, the latter composed of a large number of nerves passing from the central system into the various regions of the body.

The central system.—1. The **cerebral ganglia.** These are two nerve knots or **ganglia,** sometimes called *the brain,* united together and lying above the pharynx in the anterior part of the body cavity; Fig. 79 *cg.* From them, extending downward and backward, a pair of cords or **commissures** (Lat. *committere* = to join together), *com,* pass around the pharynx and unite with each other below on the ventral side

of the pharynx a short distance behind the mouth. 2. The **ventral cord.** When the two commissures have united they form a cord which passes to the posterior end in the median line of the body, closely attached to the body wall beneath the intestines; this is the **ventral cord,** *v.* In each segment the cord is slightly enlarged to form what is called a **ganglion**; see Fig. 80 *vc.* At the posterior end of the body this cord becomes smaller and finally terminates.

The peripheral system.—The **nerves** which form the peripheral system are numerous. From the cerebral ganglion two large nerves arise, which soon divide into many branches and pass forward to the prostomium, giving it a very large nerve supply and making it a very sensitive organ; Fig. 79. From the commissures extending around the œsophagus arise the nerves that supply the second and third segments of the body. From the ventral cord in each of the segments, from the fourth to the posterior end of the body, there arise three pairs of nerves. Two pairs arise from the ganglionic enlargement and one pair from the sides of the ventral cord behind the septum that separates each segment from the next.

Reproductive System.—The only method of reproduction in the earthworm is by sexual process.* The two sexes are, however, combined in the same individual, so that the earthworm is what is called an **hermaphrodite**; see page 251.

Female reproductive organs.—In the thirteenth segment there is a pair of small glands called **ovaries,** situated on the ventral side of the body cavity close to the middle line; Fig. 80 *ov.* In the same segment is the opening of a funnel which leads into a short tube passing through the septa into the next posterior segment. Here it is slightly enlarged to form an **egg sac,** and from the sac a small duct extends through the body wall to the exterior, opening upon the ventral surface of the fourteenth segment. These ducts are the **oviducts,** *od,* and through them the eggs produced by the ovary pass to the

*The earthworm has a slight power of regeneration of lost parts, but this power is far less developed than in *Hydra.* If it is cut into two pieces two individuals are formed.

exterior. The openings of the reproductive organs may be seen in Figure 74.

Male reproductive organs.—In the tenth and eleventh segments there is a pair of glands, the **spermaries,** *sp,* in which are formed the male reproductive elements. In these two segments their position corresponds to the position of the ovary in the thirteenth segment. They are very small glands and can only be seen by microscopic examination. Behind each of these sperm glands is a funnel-shaped, ciliated opening, leading into a tube which passes through the septa into the next segment, where it is slightly coiled, and then passes backward. The tubes from the two sperm glands on each side unite with each other in the twelfth segment to form a single duct, which passes back through the septa to the fifteenth segment, where it opens through the body wall to the exterior. This duct is known as the **vas deferens** (Lat. *vasa* = vessel + *deferens* = carrying down); Fig. 80 *vd.* In the ninth, tenth, and eleventh segments are large sacs known as **seminal vesicles,** *sv,* which serve as a storehouse for the secretion of the sperm glands, before these secretions pass to the exterior through the vas def-

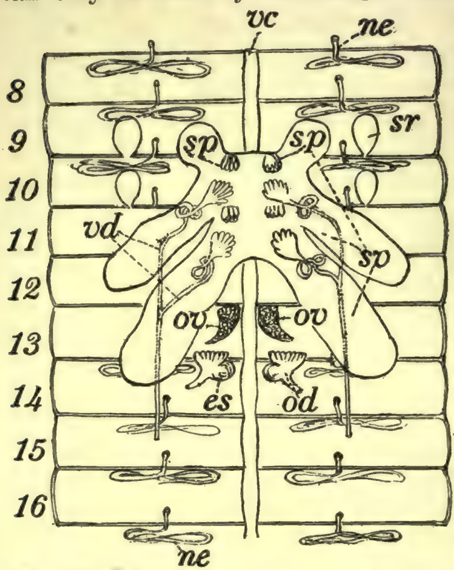

FIG. 80.—DIAGRAM SHOWING THE REPRODUCTIVE SYSTEM OF THE EARTHWORM

The numbers represent the number of segments.

es, egg sac; *ne*, nephridia; *ov*, ovary; *od*, oviduct; *sp*, spermaries; *sr*, seminal receptacles; *sv*, seminal vesicles; *vc*, ventral nerve cord; *vd*, vas deferens.

erens. At the junction between the ninth and tenth, and between the tenth and eleventh segments, may be found two pairs of white sacs, each opening to the exterior by an opening at the junction line between the segments. These are the **seminal receptacles,** *sr*, and their function is to receive the secretions from the seminal glands in copulation.

Copulation and Egg Laying.—Although the earthworm is an animal producing both male and female elements in the same individual, the habits of the animal are such that there is no fertilization of the egg by the sperm of the same individual that produces the egg, but a **cross fertilization** always occurs between two individuals. At the breeding season, which is early in the summer, two individuals place themselves side by side with their heads in opposite directions, and by means of the secretions from the glands in their skin there is formed a slimy covering that holds the two individuals in close contact (*copulation*). In this position, each transfers sperm material (see Chapter XII) from its sperm glands into the seminal receptacles of the other, after which they separate. During copulation, or immediately afterwards, a secretion is produced by the clitellum, which forms a band around the animal that extends from the twenty-eighth to the thirty-fifth segment of the body. At the close of copulation, after the animals have separated, this band is gradually pushed forward until it finally slips off over the head. As the band passes forward over the fourteenth segment a certain number of eggs are extruded into it from the oviduct; and when it passes over the ninth and tenth segments some of the sperm material from the seminal receptacles is also ejected into it. As it passes off over the head it closes up by its own elasticity. Inside of this band the eggs of each individual are thus mixed with the sperm from the other individual and cross fertilization occurs. This case holding the eggs and sperms is now known as a **cocoon,** and within it the eggs develop into earthworms. The cocoons are deposited in the soil and may be found early in the summer.

MICROSCOPIC ANATOMY OR HISTOLOGY

The body of the earthworm is made of large numbers of cells of great variety in form and structure. The cellular structure in some of the organs of the body can readily be made out under the microscope, but in others the cells can be seen only by special methods. The most important features of the histology are as follows: —

Body Wall.—The body wall contains several layers; Fig. 81. On the outside a very thin **cuticle** covers the whole body,

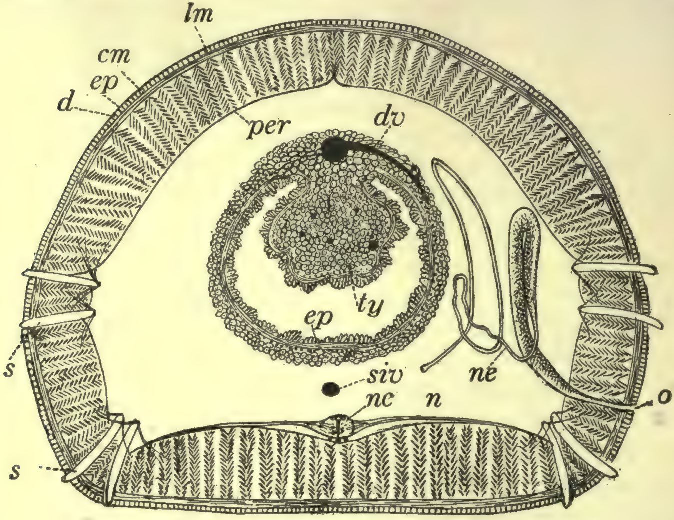

FIG. 81.—DIAGRAM REPRESENTING A CROSS SECTION OF THE EARTHWORM'S BODY

Showing the microscopic anatomy.

cm, circular muscles;
d, dermis;
dv, a branch from the dorsal blood vessel;
ep, epithelium;
lm, longitudinal muscle;
n, nerve;
nc, ventral nerve cord;
ne, nephridium;
o, opening of the nephridium;
per, peritoneum;
s, setæ;
siv, subintestinal vessel;
ty, typhlosole.

perforated, however, by numerous openings through which the various secretions pass. Inside of the cuticle is a somewhat thicker layer of cells mainly cylindrical in form, known as

the **epidermis,** *ep.* Some of the cells are **sensory cells;** others have the power of secreting a slimy material which keeps the surface of the animal moist, and these are called **gland cells;** Fig. 82. Under the epidermis is a layer of **circular muscles,** *cm,* extending around the body, each muscle in the form of a very long, slender fiber, tapering at both ends. Extending around the body as they do in a circular direction, their contraction will tend to constrict the body and reduce its diameter. Under this is a thicker layer of muscles, running lengthwise, the **longitudinal muscles,** *lm.* These are arranged in bundles and in a cross section they appear to radiate like a feather, but each longitudinal muscle fiber has the same structure as the circular muscles. By their contraction the animal's body is shortened. Under the longitudinal muscles is an extremely delicate layer of flat cells forming a thin membrane bounding the body wall on the surface lying next to the body cavity. This is the **peritoneal** (Gr. *peri* = around + *teinein* = to stretch) **epithelium,** *per.*

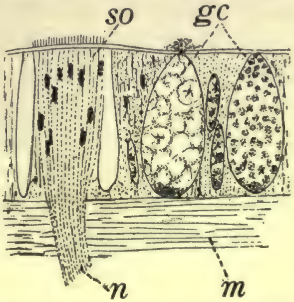

Fig. 82.—Highly magnified section of the skin of the earthworm

gc, gland cells;
m, muscles;
n, nerve;
so, sensory nerve cells.

(Modified from Dahlgren and Kepner.)

Eight delicate bristles, called **setæ,** extend through the muscle layers of the body wall and protrude through the skin, Fig. 81 *s.* They are arranged in four groups, two in each segment, and are attached by several minute muscles on the inner end. By means of these the setæ may be slightly extruded, or moved to and fro so that the tips may be directed forward and backward. If the earthworm is pulled gently through the fingers, the projecting setæ may be felt as a slight roughness on the skin.

Motion.—The motor system of the earthworm is extremely

simple and crude, consisting only of the two layers of muscles, longitudinal and circular, and the setæ. The method of its action is as follows: By the contraction of the circular muscles the diameter of the body is reduced, and, inasmuch as the body cavity is filled with the perivisceral liquid, and liquids are incompressible, the contraction of the diameter of the body must necessarily increase its length. The ends are thus pushed apart; but the setæ pointed backward act as anchors, and the pushing of the two ends of the body apart will tend to push the head forward, the rest of the body remaining practically stationary. After the contraction of the circular muscles the longitudinal muscles are contracted, thus shortening the length of the body and at the same time increasing its diameter. As the body shortens, the tail is pulled forward toward the head, the setæ again serving as anchors to prevent the body from moving in the wrong direction. Thus by alternately contracting the circular and longitudinal muscles, the head is pushed forward and the tail is pulled up to the head. If the earthworm wishes to move backward, it needs only to contract the muscles connected with the setæ and to point them forward, when they will serve as anchors to prevent the body from being pushed forward; and the alternate contraction of the two layers of muscles will make the animal move backwards. This alternate contraction of the muscles does not occur the whole length of the body at once, but sections may contract or relax, causing waves of contraction to extend from one end of the animal to the other. This method of locomotion is very inefficient for an animal living on a flat surface, and the earthworm is only able to move slowly upon the ground. In his underground burrows, however, where the animal nearly fills up the burrow, the method of locomotion is much more efficient and enables the animal to move with considerable rapidity.

Alimentary System.—As shown in Figure 83, the alimentary canal consists of five layers. On the very inside next to the cavity of the intestine is a layer of **epithelial cells** (Gr. *epi* =

upon + *thele* = nipple), *ep*, which secrete the digestive fluids and also aid in the absorption of the food. Just outside of these is a layer of **blood vessels,** *v*. A third layer consists of **circular muscle fibers** extending around the intestine, *cm*, and outside of this is a layer of **longitudinal muscles,** *lm*. A fifth layer on the outside consists of a thick coat of cells known as **chlorogogen cells,** *c*. These cover the intestine with a thick layer on its outer surface and also form the substance of the typhlosole, which, as shown in Figure 81, lies within the cavity of the intestine. The function of the chlorogogen cells is not known, though it is probable that they have something to do with the absorption of food and possibly have a function of secretion. On either side of the œsophagus in the tenth, eleventh, and twelfth segments are three pairs of white bodies known as **calciferous glands** (Lat. *calx* = lime + *ferre* = to bear), producing a lime secretion which is poured into the intestine. Its function is probably to reduce the acidity of the food, although very little is known about these glands or their uses.

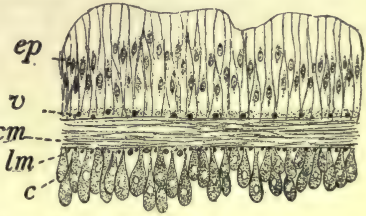

FIG. 83.—MAGNIFIED VIEW OF A SECTION OF THE ALIMENTARY CANAL

c, chlorogogen cells;
cm, circular muscles;
ep, epithelium, lining the canal;
lm, longitudinal muscles;
v, blood vessels.

(Modified from Sedgwick and Wilson.)

The Nervous System.—The microscopic study of the nervous system of the earthworm, as well as of all higher animals, has shown that while there are several kinds of cells in it, the chief ones, and probably the only ones possessing nervous functions, are large cells called **neurons.**

Neurons.—A single neuron of the earthworm is shown in Figure 84 *A*. It has a rather irregular rounded body, with a prominent nucleus, and from it arises a long process, much longer than appears in the figure. Side branches of this proc-

ess may be seen near the cell body. Other much shorter processes arise also from the cell body and divide quickly into branches. The long fiber is called the **axon** or the **nerve fiber,** and the other branching projections are called **dendrites** (Gr. *dendron* = tree). Sometimes the axons at their outer or peripheral end break up into numerous branches known as

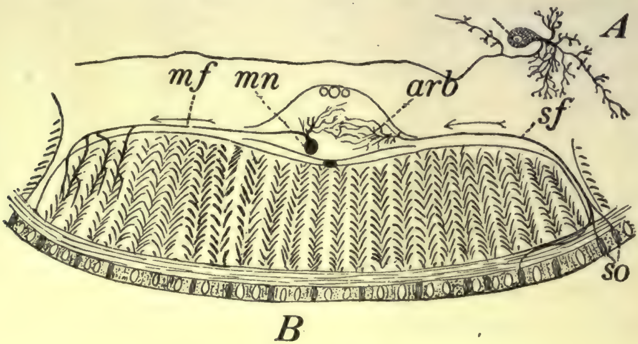

FIG. 84

A, a single neuron; *B*, a section of the ventral surface, showing the nerve cord and its connection with the muscles and dermis.

arb, arborization of an afferent nerve;
mf, motor fiber;
mn, motor nerve cell;
sf, sensory nerve fiber;
so, sensory organ.

arborizations (Lat. *arbor* = tree), *arb*. In such a neuron impulses enter the cell body through the dendrites and pass out through the axon.

Similar neurons make up the nervous system of all animals which have been carefully studied. In shape the neurons are quite varied (Fig. 85), but in all cases there is a cell body with one or more branching processes arising from it; and an axon fiber of varying length extends outward from the cell.

Vast numbers of these neurons are aggregated together to make the nervous system of the earthworm. The cerebral ganglia contain them in great numbers, and the many nerves shown in Figure 79 are formed chiefly of bundles of the axons of the neurons, whose cell bodies are either in the ganglia or at the

outer ends of the nerves, in the prostomial lobe, etc. The ventral cord also is a mass of neurons, and since it is simpler than the brain it may be more easily understood and will illustrate better the relation of neurons to the rest of the body.

FIG. 85.—NEURONS OF VARIOUS TYPES FROM HIGHER ANIMALS

A, a complex of neurons from the cerebrum; *B* and *C*, neurons from the cerebellum; *D*, a single neuron from the cerebrum.

The ventral cord.—A cross section of the cord shows it to be covered on the outside by a thin layer of epithelium, the **peritoneum,** inside of which is a muscular sheet containing a few blood vessels; Fig. 86. Near the dorsal surface of the cord are three clear rods running lengthwise, called **giant fibers,** *g*, containing nerve fibers. The cord itself is really two cords fused together. Embedded in the cord may be seen many large cells, which are the bodies of the neurons making up the cord; and extending out to form the nerve fibers which arise from the cord are the axons of these neurons.

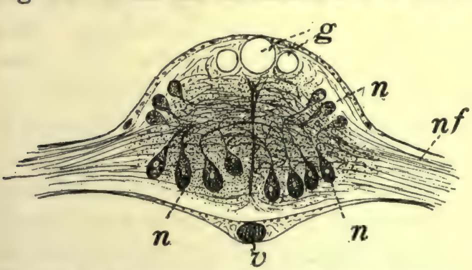

FIG. 86.—MAGNIFIED SECTION OF THE VENTRAL CORD OF THE EARTHWORM

g, giant fibers; *n*, neurons; *nf*, nerve fibers; *v*, blood vessels.

The relation of these neurons to the body may be seen from Figure 84. Most of the cells which appear so prominently in the cord have connections as shown at *mn*. Each has a complex of dendrites which branch in the substance of the cord, and a single axon which passes out through the nerve to be finally distributed to the muscles. These neurons send impulses to the muscles and are called **motor cells.** Some send their axons to muscles on the same side, as shown in the figure, and others send theirs across the cord to the muscles on the other side of the body. These axons are known as **efferent** (Lat. *ex* = out + *ferre* = to bear) **nerve fibers.** Some of the axons do not pass out of the cord, but simply connect different parts of the cord itself.

The neurons which carry impulses from without toward the center are called **afferent** (Lat. *ad* = to + *ferre* = to bear) **neurons.** These never have their neuron bodies within the cord but somewhere outside it. Many of them take their origin in special cells called **sense cells** (Fig. 84 *so*), which are sensitive to certain external stimuli. The impulses excited in the cell pass over the axon to the ventral cord. Where the axon enters the cord it breaks up into numerous branches, or **arborizations,** *arb*, which spread out in the cord itself. The impulses entering by the axons may pass from the arborizations to the dendrites of the motor cells and excite them to action. Hence a stimulus applied to the skin may produce a movement.

The sense organs.—The cells at the end of the afferent nerves constitute the **sense organs,** and they are so constructed as to be influenced by different external forces. The earthworm has no eyes, although some of its sense organs appear to be slightly affected by a bright light. They have no ears and no sense of sound, though they are very sensitive to a slight jar. They have a sense of taste, located in the mouth, and also a sense of smell. None of the sense organs is visible to the naked eye, but they may be seen by microscopic study. The end of the

prostomial lobe is the most sensitive part of the body; here the sense cells are most abundant and here the nerve supply is the largest; Fig. 79.

LABORATORY WORK ON THE EARTHWORM

Only large specimens should be used. These can be purchased from dealers in natural history supplies or they may be collected by searching with a lantern on a dark night, when they may be found stretched out on the ground and thus readily collected. A little care and experience is needed to do this without disturbing them, for they are very sensitive to the slightest jar and quickly retreat into their burrows.

The specimens should first be studied alive, if possible, to see the contraction of the dorsal blood vessel and the contractions of the body in locomotion. The setæ may be felt by drawing the body gently through the fingers, and they can be examined under a lens.

If the worms are to be dissected, or preserved for future use, they should be treated as follows: Place the worms in a shallow dish with wet filter paper torn into shreds. The animals will swallow it and as it passes through the alimentary canal it will carry the dirt from the canal. This part of the process is not necessary unless microscopic sections are to be made. If they are to be kept simply for dissection, they can be preserved at once as follows: —

Place a number of worms in a shallow dish with just water enough to cover them. Add a few drops of alcohol, and, after a few moments, add a little more. Continue adding the alcohol gradually until the animals have become motionless and relaxed. This process should take at least two hours. Then transfer them to a large shallow dish containing 50% alcohol, straightening the animals out, and laying them side by side. After an hour replace the 50% alcohol with 70%; after a few hours change again to a fresh lot of 70% alcohol. Finally the animals are to be placed in 90% alcohol. It is important to keep them straight in this final hardening fluid, and this may be done by laying them out on rather stiff paper, without touching each other, and rolling them, putting about a dozen in each roll. This will hold them in proper shape, and the rolls may be stored in tall jars and will keep indefinitely.

Animals so preserved will serve either for microscopic sections or for dissection. Sections should be made by the instructor and, after staining, should be mounted and furnished the student for study.

For dissection, the animal should be placed, under water, in a tray containing dissecting wax. The anterior end is pinned down and then,

with fine scissors, an incision is made along the dorsal median line, from the head to the posterior end of the body. The body is then opened and the walls pinned out so as to disclose the internal parts. This should all be done under water. If carefully performed the internal parts may be easily worked out, a lens being used to show the smaller parts. To show the nervous system and the nephridia the alimentary canal should be cut through, behind the gizzard, and carefully dissected away in front. There will then be no difficulty in making out all the organs except the ovaries and spermaries. The ovaries may be found by careful study with a lens, but the spermaries cannot be found without special methods. The contents of the seminal vesicles and the ovaries should be examined with a microscope. One of the nephridia should be removed and studied with a low magnifying power.

For the study of the histology, sections should be furnished by the instructor. Animals preserved as above described are in good condition for sectioning. They should be embedded in paraffin and stained in picro-carmine. Sections through various parts of the body should be studied, and these should include at least sections through the cerebral ganglia, through the aortic arches, and through the posterior parts of the body showing the typhlosole. The study of these sections with both low and high powers will show the chief features of the microscopic anatomy. More detailed study of the histology is hardly feasible with elementary classes.

CHAPTER IX

MULTICELLULAR ANIMALS: THE FROG (RANA)

GENERAL DESCRIPTION

THE body of the frog is composed of a **head** and a **trunk,** but there is neither neck nor tail. The wide **mouth** extends far back to the end of the head. On the upper side of the head in front are two **nostrils** (*nares*) that open directly through the bones of the skull into the mouth. Farther back on either side of the head are the **eyes,** provided with two loose folds of skin which serve as **eyelids.** The upper lid is immovable, but the lower can be brought up over the eye for protection. It is called the **nictitating membrane** (Lat. *nictare* = to wink), is semi-transparent, and does not prevent sight wholly when closed. Behind the eyes are two round flat surfaces, which are membranes stretched over a shallow cavity in the skull. They are the **tympanic membranes** (Lat. *tympanum* = drum) and serve to collect sound waves and transfer them to the ears which lie within the head. The part of the body behind the anterior appendages or arms is called the **abdomen,** and the cavity within, which holds the stomach and intestines, is the **abdominal cavity.** The organs of the abdomen are sometimes called **viscera.**

Of the two pairs of **appendages,** the fore legs are provided with only four toes, while the hind legs have five toes connected by a web. The hind legs are much longer than the fore legs and are the chief organs used in locomotion. The rest of the body is smooth, gradually tapering behind and ending abruptly just above the attachment of the hind legs. Near the posterior end of the body on the dorsal side is a good-sized opening, the **cloacal aperture** (Lat. *cloaca* = sewer), which serves as the common outlet of the intestine, the kidneys, and the reproductive organs.

The whole body of the frog is covered with a smooth **skin,** which is always moist and is abundantly supplied with blood vessels, especially under the arms and on the side of the body. The skin is everywhere loosely attached to the underlying flesh and in certain rather large areas is not attached at all, large spaces being thus left between it and the flesh. These are **lymph spaces** and are filled with a clear liquid called **lymph.** When the skin is examined microscopically, it is found to be made of two layers; Fig. 87. The outer layer, the **epidermis,** *ep*, is thin, while the inner layer, the **dermis,** *d*, is quite thick. The epidermis is made of several layers; the cells of the inner layers are large, rounded, growing cells, while the outer ones are flattened and lifeless. The epidermis increases in thickness from its inner side, and is constantly wearing away on its outer side. The **dermis** is a mass of **connective tissue** fibers, among which lie **glands, blood vessels, nerves,** and numerous **pigment** (Lat. *pingere* = to paint) **cells** which give the color to the skin.

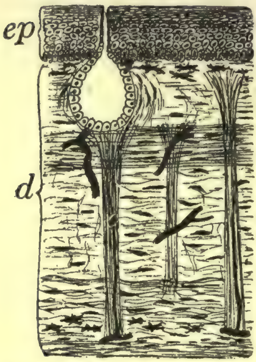

FIG. 87.—SECTION THROUGH THE SKIN OF THE FROG

ep, epidermis; *d*, dermis.

(Modified from Howes.)

The Skeleton.—The frog has an internal bony skeleton. An internal skeleton is the most distinctive characteristic of the highest animals. Animals with such a skeleton are called **vertebrates,** a group comprising *fishes*, *amphibians*, *reptiles*, *birds*, and *mammals*. No other animals except vertebrates possess true bones. This bony skeleton gives support to the softer parts, gives form to the body, serves to attach the muscles, and enables them to produce the movements of the animal. The skeleton is made of about ninety articulated bones, *i. e.*, united together at the joints. Some of these form **mov-**

able joints, in which a movement of the bones produces a movement of the body. In other joints the bones are firmly grown together forming the **immovable joints.** The bones of the skull, for example, are so firmly fused that they appear as a single bone; and the bone of the forearm (Fig. 88 *r-u*) is really made of two bones fused together. Two distinct parts of the skeleton may clearly be seen: (1) *the axial skeleton,* consisting of the skull and spinal column; (2) *the appendicular skeleton,* which forms the support for the arms and legs.

The axial skeleton.—The spinal column is composed of nine separate bones called **vertebræ**; Fig. 88 *B*. Each vertebra consists of a **centrum,** *c,* and a **neural arch,** *na,* the arch inclosing the **neural foramen** (Lat. *foramen* = opening). From each side of the arch a process of bone extends laterally, called the **transverse process** (Lat. *trans* = across + *vertere* = to turn), *tr.* On the front and back of each vertebra are two smooth surfaces where the successive vertebræ rest upon each other, *i. e., articulate* (Lat. *articulus* = joint). They are the **articular processes,** or **zygapophyses.** In their natural position the nine vertebræ are joined together by their centra, the posterior surface of one touching the anterior surface of the next; Fig. *A*. The neural foramina are thus placed opposite each other, and all together form a tube which incloses the spinal cord. The surfaces of the centra fit by a ball-and-socket joint, each of the first seven vertebræ having a ball on the posterior and a socket on the anterior surface, while the eighth is concave on both surfaces, and the ninth is convex on both surfaces. The nine vertebræ are much alike, but can be distinguished from each other. The first has no transverse process, while the centrum of the ninth has two convex posterior surfaces, and very large transverse processes. From the posterior surface of the last vertebra a long slender bone extends backward to the end of the body, the **urostyle** (Gr. *oura* = tail + *stylos* = pillar); Fig. *A*, *ur.* The

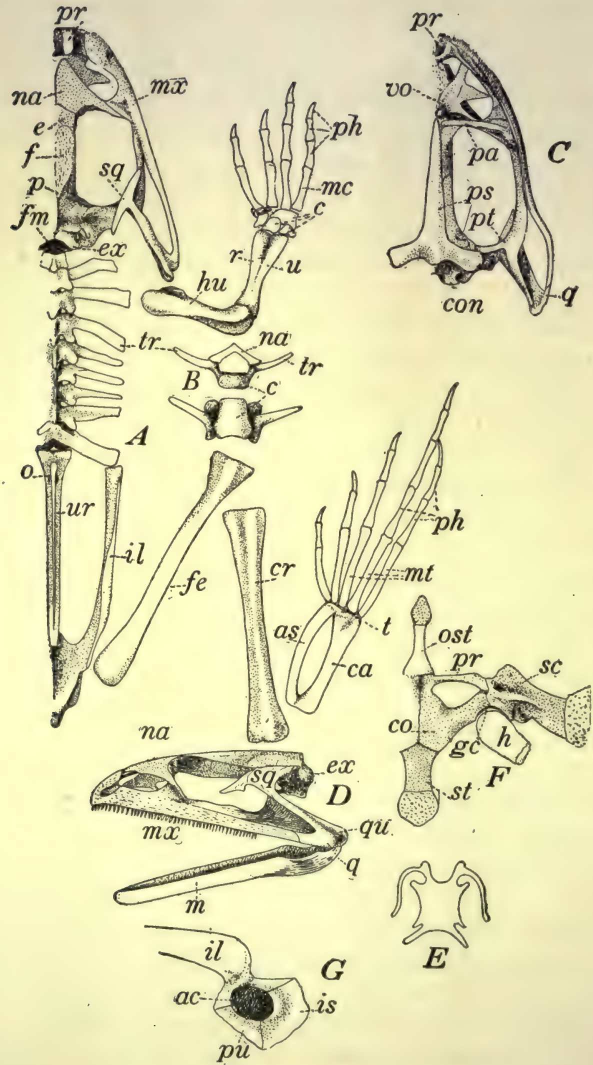

FIG. 88.—THE SKELETON OF THE FROG

FIG. 88.—THE SKELETON OF THE FROG

A, one-half of the skeleton shown from above.

as, astragalus;	*mt*, metatarsals;
c, carpals;	*mx*, maxilla;
ca, calcaneum;	*na*, nasal;
cr, crus;	*o*, opening for nerve;
e, ethmoid;	*p*, parietal;
ex, exoccipital;	*ph*, phalanges;
f, frontal;	*pr*, premaxilla;
fe, femur;	*r-u*, radio-ulnar;
fm, foramen magnum;	*sq*, squamosal;
il, ilium;	*t*, tarsals;
hu, humerus;	*tr*, transverse process;
mc, metacarpals;	*ur*, urostyle.

B, a vertebra from the end and from above.

c, centrum;
na, neural arch;
tr, transverse process.

C, the skull shown from below.

con, occipital condyle;	*pt*, pterygoid;
pa, palatine;	*q*, quadrate;
pr, premaxilla;	*vo*, vomer.
ps, parasphenoid;	

D, skull shown from the side.

ex, exoccipital;	*q*, quadrato-jugal;
mx, maxilla;	*qu*, quadrate;
m, mandible;	*sq*, squamosal.
na, nasal;	

E, the hyoid bone.

F, the shoulder girdle shown from below.

co, coracoid;	*pr*, precoracoid;
gc, glenoid cavity;	*sc*, scapula;
h, humerus;	*st*, sternum.
ost, omosternum;	

G, the pelvic girdle shown from the side.

ac, acetabulum;	*is*, ischium;
il, ilium;	*pu*, pubis.

spinal cord extends into it, but soon passes out through two small openings, on either side, *o*, as two small filaments. This bone represents the tail found in allied animals (*salamanders*). The frog has no ribs and the transverse processes end abruptly at a short distance from the centrum.

The skull.—In front the first vertebra is articulated with the **skull,** and the neural canal is continued into the skull through a large opening, called the **foramen magnum** (Lat. *foramen* = hole), *fm*. Inside the skull is a large cavity holding the brain, the **cranial cavity.** The skull itself is composed of thirty-two bones, rigidly fused together to form a solid structure. These bones, which are shown and named in Figure 88 *A* and *C*, may be divided into three groups: 1. The *cranial bones*, which form the roof, walls, and floor of the cranial cavity. The floor is made of the **basioccipital** and the **parasphenoid,** *ps;* the walls are made of the **parietals,** *p*, the **otic** bones, and the **exoccipitals,** *ex;* and the roof is made of the **supraoccipitals** and the **frontals,** *f*. 2. The *facial bones*, which form the face. These are the **nasals,** *na*, the **premaxillas,** *pr*, and the **maxillas,** *mx*, above, and the **vomers,** *vo*, below. 3. The *branchial* (Lat. *branchiæ* = gills) *skeleton*. This part of the skeleton is made primarily of two V-shaped arches, lying below the cranium with the open part of the V above, next to the skull; but the original relation of the V-shaped arches has become so modified that it is difficult to recognize. The first of the arches is the lower jaw or **mandible;** Fig. *D*, *m*. The closed part of this arch is in front where the two halves come together. At the back the two halves spread apart and pass backward to the point where the jaw articulates with the cranium at *q*. The lower jaw is from this joint held attached to the cranium by two chains of bones. One of them is made of the **quadrate** (Fig. *D*, *qu*), and the **squamosal,** *sq*, these two forming what is sometimes called the **suspensorium.** The other chain is made of two bones lying below the cranium, the **pterygoid** (Fig *C*, *pt*), and the **palatine,** *pa*. These are firmly fixed to

the cranium below. The joint is also attached to the maxilla by a little bone called the **quadrato-jugal**; Fig. *D, q*. Although in the adult frog these chains of bones are firmly attached to the cranium, they are at first free from it, and are really the upper parts of the arches below, rather than a part of, the cranium proper. The second arch is very rudimentary, only a small part of it being left in the frog. It is called the **hyoid arch.** Although in some animals this is also a well-developed V-shaped arch, all that is left of it in the frog is a flat plate, made partly of bone and partly of cartilage (Fig. *E*), which is so loosely attached to the skull that it is usually lost in prepared skulls. In the living frog it lies underneath the larynx, to which it gives support and rigidity. It is attached to the skull only by ligaments, without any bony connection.

When the skull begins to form in the young frog the parts are soft, and only, as development proceeds, does true bone form. Part of the skull forms first as cartilage, a material that is harder than membrane but softer than bone. Later within this cartilage the mineral matter is deposited, forming true bone, and the bones thus formed are consequently called **cartilage bones.** These are the *occipitals, palatines, pterygoids,* and the *mandibles.* The other bones are formed first as membranes rather than cartilage. Within the membrane the mineral bony matter is laid down, and bones developing in this manner are known as **membrane bones.** The membrane bones are the *frontals, parietals, parasphenoids, squamosals, nasals, vomers, premaxilla,* and the *maxilla.*

At its posterior end the skull is articulated with the first vertebra by means of two rounded, smooth surfaces which fit into two corresponding smooth depressions on the upper surface of the first vertebra. The articular projections are called the **occipital condyles**; Fig. *C, con.*

Appendicular skeleton.—Each appendage consists of a girdle and the appendage proper. The **shoulder girdle** is a girdle of bones surrounding the body just back of the head, and

holding the arm in position. It is shown from below and flattened out in Figure *F*. Each half consists of a **scapula,** *sc* (the dorsal part of which is made of cartilage), a **coracoid,** *co,* a **precoracoid** and a **clavicle** fused together, *pr.* At the place where the coracoid and the scapula come together is a smooth cavity into which the end of the arm articulates, called the **glenoid cavity,** *gc.* In its natural position the scapula is bent over the back, with the coracoids touching each other in the middle line below on the ventral side of the body. Behind and in front of them are two pieces of bone, the **omosternum,** *ost,* and the **sternum,** *st.* These two bones are regarded as a part of the axial skeleton.

The arm proper consists of the **humerus** (Fig. *A*, *hu*), the **radius** and **ulna** fused together, *r-u,* six wrist or **carpal bones,** *c,* and five fingers, of which the first is rudimentary. Each finger is composed of a **metacarpal,** *mc,* and several **phalanges,** *ph.* The posterior appendages have a **pelvic girdle,** made of three pairs of bones, all united into one in the adult. One of them, the **ilium,** is long and runs forward to the transverse process of the last vertebra; Fig. *A*, *il.* At its posterior end each ilium joins the other two bones, the **pubis** (Fig. *G*, *pu*), and the **ischium,** *is.* At the point where the three bones meet there is a rounded cavity for the attachment of the leg, the **acetabulum,** *ac.* The pubes and ischia of the two sides of the body are fused together on the middle line, below the urostyle. The leg consists of a **femur** (Fig. *A*, *fe*), and the **crus,** *cr,* which is really composed of a **tibia** and **fibula** fused together. Following the crus are the bones of the foot, consisting of two slender bones, the **astragalus,** *as,* and **calcaneum,** *ca;* then come two extremely small **tarsal bones,** *t,* and finally a series of **metatarsals,** *mt,* and **phalanges,** *ph.*

Muscular System.—Most of the bones of the skeleton are more or less movable one upon the other at the articulations. The muscles which move them are numerous and complicated. Each muscle is an elongated mass of contractile tissue, which

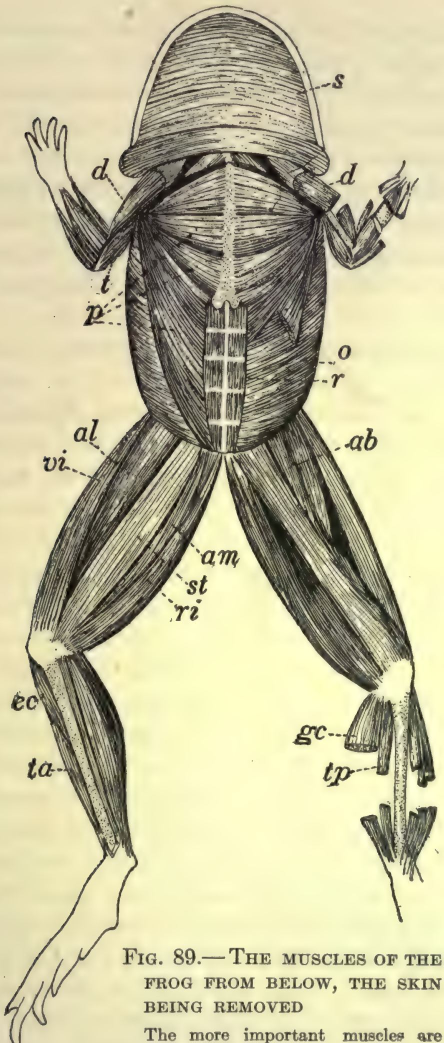

FIG. 89.—THE MUSCLES OF THE FROG FROM BELOW, THE SKIN BEING REMOVED

The more important muscles are named as follows:—

ab, adductor brevis;
al, adductor longus;
am, adductor magnus;
d, deltoid;
ec, extensor cruris;
gc, gastrocnemius;
o, obliqus;
p, pectoralis;
r, rectus abdominis;
ri, rectus internus major;
s, submaxillaris;
st, sartorius;
t, triceps;
ta, tibialis anticus;
tp, tibialis posticus;
vi, vastus internus.

is usually attached at the ends to two separate bones, the term **origin** being applied to the attachment nearest to the center of the body, and **insertion** to the attachment the farthest from the center; muscles pull in the direction of their origin. Since these muscles are numerous and attached to the bones at different places, they pull upon the bones in different directions and produce a great variety of movements. Figure 89 shows the chief muscles of the frog. The names given to them are the same as those applied to the corresponding muscles in man.

Joints or Articulations.—Where two bones come together they form a joint. In some cases the bones are so rigidly grown together that there is no motion between them, thus forming the **fixed joints,** like those that are between the bones which form the skull. In other places the bones are freely movable, forming the **movable joints.** All the movements of the body are produced at the joints. The bones at these joints are so connected that, while they are held firmly together, they are at the same time freely movable. The ends of the bones are generally more or less rounded, the end of one bone fitting into a rounded depression on the other. The ends of the bones are also covered by a layer of cartilage, which is quite smooth so as to prevent friction. This structure makes it possible for one bone to move upon the other without difficulty. All friction is eliminated, and movement of the bones is rendered easier, by a secretion of fluid which is poured into the joint from the **synovial glands.** This is called the **synovial fluid.** To prevent the bones from being pulled apart they are held together by bands of white connective tissue called **ligaments.** These are tough but flexible, and are attached to the two bones that form the joint. They are long enough to make the motions of the bones free, but short enough to hold them in position and prevent their being pulled away from each other by slight strains. The bones are held firmly in position by the muscles. The muscles which move the bones usually have

their origin on the bones above the joint, and their insertion on the bone below. The muscles end in bands of connective tissue called **tendons** that extend down over the joint to the insertion on the lower bone. The muscles are always tightly stretched in the body and always pulling upon the tendons. As a result the tension upon the tendons holds the two bones of the joint in firm contact. Outside of the muscles and tendons is the skin. The joint thus consists of smoothly moving bones, which are moistened by synovial fluid, held in position by tightly drawn tendons, prevented from being pulled apart by ligaments that protect them against strains, and moved by muscles.

The freedom of motion in the different joints varies with the shape of the bones at the joints. In some of the articulations, one bone ends in a ball which fits into a rounded socket of the other bone. In this type, the **ball-and-socket joint,** the bones are freely moved in any direction. The joint at the hip and that of the shoulder are examples of this type. In other joints the form of the bones is such that motion is possible only backward or forward. These are called **hinge joints,** and are illustrated by the joints at the elbow, the knee, the wrist, and by the separate joints of the fingers and toes. In some joints one bone moves around the other as on a pivot. No good examples of this are found in the frog, but in the human body the motion of turning the head, or turning over the hand so that the back or the palm is uppermost, are excellent illustrations. It is evident that the movements of the body are dependent upon the free motion of the bones at the joints, and that the growing of the bones together at a joint, **anchylosis** as it is called, will destroy all power of motion.

Alimentary Canal.—The wide mouth (*oral opening*) leads into a very large cavity, the **buccal cavity.** There are **teeth** on the maxilla, premaxilla, and vomer (Fig. 88 *C*, *D*), which are of use for holding, but not for masticating food. On the floor of the mouth is a large muscular **tongue,** attached to

the base of the mouth in front, and free behind. Owing to this attachment, the back part of the tongue can be thrown out of the mouth for a considerable distance, serving as an important organ for capturing insects. Just back of the tongue on the floor of the mouth is a narrow slit, the **glottis,** leading into a tube, which passes to the lungs. Behind the glottis is a larger opening leading to the **œsophagus,** and hence to the stomach. The **nostrils** open in the mouth through the roof in front (**internal nares**); and a pair of openings in the back part of the roof leads to the ears, the **eustachian openings.**

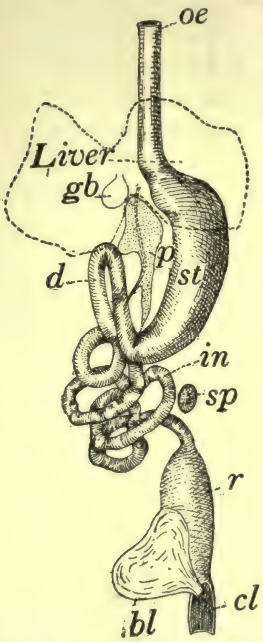

FIG. 90.—THE ALIMENTARY TRACT OF THE FROG

bl, bladder; *cl*, cloacal cavity; *d*, duodenum; *gb*, gall bladder; *in*, intestine; *oe*, œsophagus; *p*, pancreas; *sp*, spleen; *st*, stomach; *r*, rectum.

If a slit be made through the skin and flesh of the abdomen, passing forward on the ventral middle line through the sternum, and the body opened, most of the internal organs can be seen. The œsophagus passes directly backward about halfway to the end of the body, where it expands into a large chamber, the **stomach** (Fig. 90 *st*), which extends obliquely across the body towards the right. The lower part of the stomach is called the **pylorus;** this passes down into a small tube which makes a U-shaped bend, called the **duodenum,** *d*, and then forms several coils which constitute the **intestine,** *in*. Finally the tube passes into a large but short chamber, the **rectum,** *r*, which communicates with the exterior through the **cloacal opening.** In front of and to the right of the stomach is the large several-lobed **liver.** This secretes a liquid called **bile,** which

passes by a duct into the **gall bladder,** *gb,* where it is stored for a while and from which it later passes through the bile duct into the duodenum, close to the pyloric end of the stomach. In the bend of the U formed by the duodenum and the stomach, is a slender, yellowish body, the **pancreas,** *p,* which empties into the duodenum by the **pancreatic duct** opening close to the bile duct. The lining of the whole alimentary canal is called the **mucous membrane.**

The whole intestine is slung in position by a thin sheet of membrane, which passes around the intestine and then becomes attached to the abdominal wall. This is the **mesentery,** and is really a fold of a large membrane that completely lines the body cavity, the **peritoneum.** The relations of the peritoneum, mesentery, and intestine are shown diagrammatically in Figure 91. In the mesentery are many nerves and numerous blood vessels which carry nutrition from the intestine. The mesentery surrounds not only the intestine, but also the liver and the pancreas. In its folds below the stomach is a rounded red body, the **spleen;** Fig. 90 *sp.*

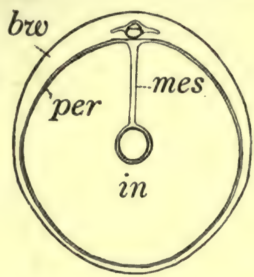

FIG. 91.—DIAGRAM REPRESENTING A CROSS SECTION OF THE BODY

bw, body wall;
in, intestine;
mes, mesentery;
per, peritoneum.

Circulatory System.—The circulatory system of the frog, like that of the earthworm, consists of blood inclosed in a network of blood vessels; but it is a more definite system and the blood flows in a more regular course. It consists of a true *heart,* and *blood vessels.*

The **heart** is situated beneath the shoulder girdle, in front of the liver and is surrounded by a thin sac, the **pericardium** (Gr. *peri* = around + *cardia* = heart). The heart itself is made up of a sac divided into three chambers, the walls of which are masses of muscles. The fibers of these muscles run

in every direction, so that when they contract (*systole*) the heart is diminished in size and the blood that is in the cavities is squeezed out; when they relax (*diastole*) the heart expands again and the blood flows into it. Figure 92 shows a diagram of the heart structure, cut open so as to show the interior of the cavities. At the anterior end are two cavities, the right and the left **auricles,** *ra* and *la;* the right, which receives blood from the body, being much larger than the left, which receives blood from the lungs. These two chambers are separated by a partition. At the lower side of the auricles each opens into the **ventricle,** *v,* the third and largest chamber below. The openings between the auricles and ventricle (shown by the arrows in Fig. 102), are guarded by **valves,** which are flaps of membrane, so situated that they allow blood to flow readily from the auricle into the ventricle, but close up at once if the blood starts to flow back into the auricle, as it would do when the ventricle contracts, did not these valves block the passage. The ventricle is a large chamber, partly divided by partitions. Leading out of it in front is a large blood vessel. This extends forward, on the ventral side of the heart, and at the anterior end of the heart it divides into two arteries, one turning to the right and one to the left. The large vessel is called the **bulbus arteriosus,** *ba,* and its two branches are the **aortæ,** *ao.* This bulbus receives the blood which is forced out of the heart when it contracts. Within it, and at the beginning of the aortæ, are **valves** which control the flow of the blood, as will be described on a later page. On the dorsal side of the heart is a large thin-walled chamber, the **venus sinus** (Fig. 92 *B, vs*), into which open the veins that bring the blood back from the body. This sinus opens into the right auricle, which thus receives all the blood which flows back to the heart from all parts of the body, except the lungs. The blood from the lungs empties into the left auricle by two small veins, one from each lung; Fig. 92 *pv.*

The blood vessels ramify all over the body in a very complex

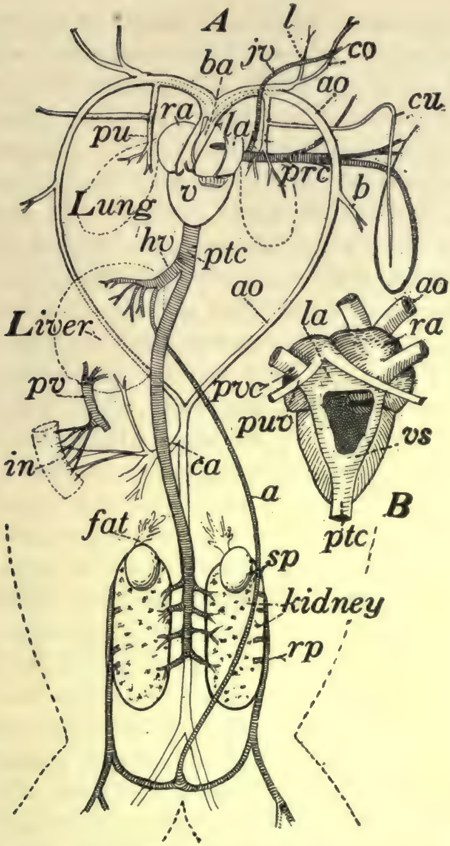

FIG. 92. — DIAGRAM OF THE CIRCULATION OF THE FROG

The veins are represented in shaded lines and those entering the heart from in front are shown only on one side. *A*, the general circulation shown from below.

a, abdominal vein;	*hv*, hepatic vein;	*pu*, pulmonary artery;
ao, aorta;	*in*, intestine;	*pv*, portal vein;
b, brachial;	*jv*, jugular vein;	*ra*, right auricle;
ba, bulbus arteriosus;	*l*, lingual artery;	*rp*, renal-portal vein;
ca, cœliac axis;	*la*, left auricle;	*sp*, spermary;
co, carotid artery;	*prc*, pre vena cava;	*v*, ventricle.
cu, cutaneous artery;	*ptc*, post vena cava;	

B, The heart from below, showing the venus sinus cut open.

ao, aorta;	*puv*, pulmonary vein;	*ptc*, post vena cava;
la, left auricle;	*pvc*, pre vena cava;	*vs*, venus sinus.
ra, right auricle;		

system. The **arteries,** which take blood away from the heart, are thick-walled and elastic; while the **veins,** which bring it back again, are thin-walled. The distribution of the chief blood vessels is shown in Figure 92. The bulbus arteriosus soon divides into two branches that turn backward and finally unite with each other in the abdomen beneath the stomach. These two branches, the **aortæ,** *ao,* give off in their course many vessels, the chief of which are the **lingual** to the tongue, *l,* the **carotid** to the head, *co,* the **brachial** to the arms, *b,* and the **cœliac axis** to the organs of the abdomen, *ca.* After dividing many times into smaller and smaller branches, the arteries finally break up into an immense number of minute thin-walled vessels called **capillaries** (Lat. *capillus* = hair). These are microscopic, but of great importance, since all of the interchanges between the blood and the tissues of the body take place through them; Fig. 101. The blood, after passing through the capillaries, enters again into a series of vessels of constantly increasing diameter and finds its way back to the heart. These larger returning vessels are **veins,** and they unite with others, until finally a few large veins are formed which empty into the sinus; Fig. 92 *B.* The blood vessels thus form a closed system, and the blood that leaves the heart returns without leaving the vessels. The blood that goes to the intestine by the cœliac axis, *ca,* passes through two series of capillaries before again entering the heart. It first passes into capillaries in the intestine, where it receives nutriment absorbed from the food; then it is collected into a large vein, the **portal vein,** *pv,* which enters the liver, and breaks up into another system of capillaries; then, by the way of the **hepatic vein** (Gr. *hepar* = liver), *hv,* it enters into the large **posterior vena cava** (Figs. *A* and *B*, *ptc*), which leads to the venus sinus. This system of veins and capillaries in the liver is called the **portal system.** Part of the blood that goes to the legs also has a double system. It first enters the capillaries in the muscles of the legs, and on its way back a part of it passes

through the kidneys, where it is again broken up into capillaries. This is the course of the blood which returns from the leg through the **renal-portal vein** (Fig. 92 *rp*), but the rest of the blood from the legs is diverted to an **abdominal vein,** *a*, which enters the heart without passing through the liver. Both the liver and the kidneys have their own supply of blood from the aorta, as well as that received from the veins.

The vessels thus far described are called the **systemic circulation,** in distinction from the **pulmonary circulation,** which is the circulation in the lungs. The **lungs** are elastic bags (Fig. 92), capable of much expansion when inflated with air, but collapsing if the air is removed. They are connected with the mouth by the **larynx,** which opens at the base of the tongue through the **glottis.** Through the glottis and the larynx air is taken into the lungs to purify the blood. The arteries which supply the lungs, the **pulmonary arteries,** *pu*, arise from the main arteries near the heart. From each of these an artery is given off to the skin under the arm, the **cutaneous,** *cu*. Since in the lungs the blood is purified by the oxygen of the air, and through the skin it is purified by the oxygen in the water, the frog can live either in the water or in the air, *i. e.*, it is *amphibious*. The blood that is purified in the lungs enters the heart again by a **pulmonary vein,** *puv*, which flows into the left auricle. The pure blood in the left auricle is thus kept separate from the impure blood in the right auricle, but as soon as the auricles contract the blood of both auricles is forced into the single ventricle, and intermingles. Although the blood in the ventricle is really mixed, still the blood upon the right side of it, since it received blood directly from the right auricle, will contain more impure blood than that on the left side, which is connected directly with the left auricle. The pure and impure blood are kept partly separate by muscular partitions extending irregularly through the ventricle.

The **blood** is composed of a colorless liquid, called the **plasma,** in which float two types of corpuscles. The larger, the **red**

corpuscles (*erythrocytes*) (Gr. *erythros* = red + *cytos* = cell) (Fig. 93 *rc*), are oval in shape; their red color is due to the **hæmoglobin,** which is in the corpuscles, instead of in the plasma, as in the case of the earthworm. The **white corpuscles** (*leucocytes*) (Gr. *leukos* = white + *cytos* = cell), *lu*, are smaller than the red corpuscles, and are able to force themselves through the walls of the capillaries, and wander indefinitely through the tissues. There is a third type of very minute bodies in the plasma, called **platelets,** of which little is known.

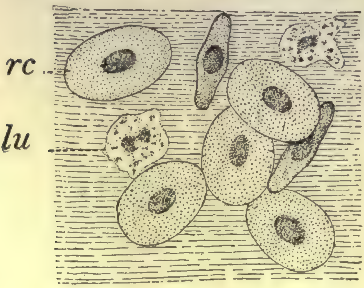

FIG. 93.—BLOOD OF THE FROG, HIGHLY MAGNIFIED

lu, leucocytes or white corpuscles; *rc*, red corpuscles.

Lymph System.—Besides the blood vessels, the frog has a system of much smaller **lymph vessels** in the skin, the intestine, and other parts of the body. These are thin walled and filled with a colorless liquid, the **lymph,** and are so delicate that they can be seen only in specially prepared specimens. In places these vessels are connected with spaces between the tissues, **lacunæ,** and with the large cavities of the body. In the intestine the lymph vessels receive a special name, the **lacteals. Lymphatic glands** are found in connection with the lymph vessels, and in the frog there are also two pairs of **lymph hearts,** whose contraction propels the lymph in its circulation.

The Nervous System.—The nervous system consists of: (1) *The cerebrospinal axis,* (2) *The cranial nerves,* (3) *The sympathetic system.*

Cerebrospinal Axis.—The brain and spinal cord are on the dorsal side of the animal, within the neural canal and the cavity of the skull; Fig. 94. The **brain** consists of several distinct parts. Beginning in front they are as follows: The

olfactory lobes, *ol,* the **cerebral hemispheres,** *ce,* the **thalamencephalon,** *th,* the **optic lobes,** *op,* the **cerebellum,** *cb,* and the **medulla oblongata,** *m.* The cerebellum is very small, and the medulla appears to be only an enlarged continuation of the spinal cord. In the latter there is a large triangular cavity, roofed over by a thin membrane containing blood vessels (**choroid plexus**). The cavity is called the **fourth ventricle,** and it communicates with other cavities in the brain. On top of the thalamencephalon is a small body, the **pineal gland** or the **epiphysis,** *pi.* The under side of the thalamencephalon is produced into a process directed backward, the **infundibulum,** which ends in another small body, the **pituitary body** or the **hypophysis.**

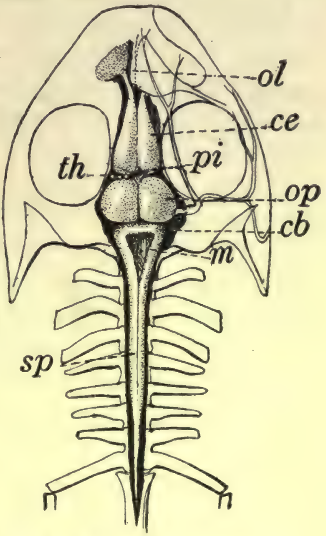

FIG. 94.—THE CENTRAL NERVOUS SYSTEM

Shown in position in the skull and spinal column.

cb, cerebellum; *ce,* cerebrum; *m,* medulla oblongata; *ol,* olfactory sac; *op,* optic lobe; *pi,* pineal body; *sp,* spinal cord; *th,* thalamencephalon.

The cerebrum and thalamencephalon together constitute the **forebrain,** the optic lobes form the **mid-brain,** and the cerebellum and medulla form the **hind-brain.** The relative development of these different parts varies widely in different animals, and in the higher vertebrates the cerebrum becomes much the largest part of the brain, this development reaching its maximum in the human species.

From the posterior part of the medulla **the spinal cord,** *sp,* extends through the spinal column, tapering to a minute filament, which extends a short distance into the urostyle. The brain and spinal cord are covered by two membranes, an outer

tough one called the **dura mater,** and a more delicate, inner membrane, the **pia mater.**

The Craniospinal Nerves.—Twenty pairs of nerves arise from the brain and cord, — ten from the brain, and an equal number from the cord. Those from the brain, the **cranial nerves,** supply the organs of special sense and the muscles and other organs of the head, the heart, lungs, and stomach. They are as follows: —

1. The *olfactory nerves,* from the olfactory lobes supplying the nasal cavities.
2. The *optic nerves.* These two nerves arise from the optic lobes, cross each other to form the optic *chiasm,* and then each passes to the eye on the opposite side of the head.
3. *Motor ocularis,* supplying the muscles of the eye.
4. *Patheticus,* supplying the muscles of the eye.
5. *Trigeminal,* supplying the sides of the head (sensory).
6. *Abducens,* supplying the muscles of the eye.
7. *Facial,* supplying the sides of the head (chiefly motor).
8. *Auditory,* supplying the ear.
9. *Glossopharyngeal,* supplying the pharynx and the tongue (sensory).
10. *Pneumogastric,* supplying the larynx, the heart, and the stomach.

From the spinal cord arise ten pairs of **spinal nerves,** one between the skull and the first vertebra, and one between each vertebra and the next; Fig. 95. The first supplies the tongue (motor); the second and third unite to form the nerve going to the arm, the **brachial nerve** (Lat. *brachium* = arm); the fourth, fifth, and sixth supply the middle region of the body; and the seventh, eighth, and ninth unite by cross branches to form the **sciatic plexus** (Lat. *plectare* = to braid), from which arise the nerves that supply the leg, the **sciatic nerve,** which is the largest in the body; the tenth nerve supplies the region of the urostyle. Each nerve arises from the cord by two roots, of which the **anterior root** carries impulses away

from the brain (efferent fibers), and the **posterior root** carries impulses toward the brain (afferent fibers).

The Sympathetic System.—In the abdominal cavity, lying on each side of the spinal column, is a chain of minute nerve ganglia, ten in number, which are also connected with the spinal nerves; Fig. 95 *sy*. These constitute the **sympathetic system.** From these two chains of ganglia minute nerves are given off, chiefly to supply the intestine, the kidney, and the other organs of the abdomen. Although connected with the spinal nerve, the sympathetic system is quite distinct and has special functions.

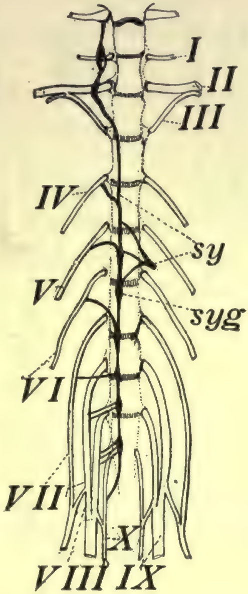

FIG. 95.—DIAGRAM SHOWING THE RELATION OF SYMPATHETIC SYSTEM TO THE SPINAL NERVES

The sympathetic chain of one side only is shown. The spinal nerves are indicated by Roman numerals; *sy*, sympathetic nerve; *syg*, sympathetic ganglia.
(Modified from Parker.)

The microscope shows that the nervous system, like that of the earthworm, is composed of an enormous number of *neurons*, each with its *cell body*, *dendrites*, and *axon*. These are massed in the brain and cord, and there are many also in the ganglia outside of the cord. They are so situated that part of them carry impulses to the center, and part of them carry them in the reverse direction. Their numbers are greater and their relations more complex than those of the earthworm.

The Sense Organs.—At the peripheral end of all of the sensory nerves are found very complicated organs, constructed so as to be affected by certain external stimuli. When they are stimulated impulses start from them and pass over the afferent nerves to the brain, where they become sensations. They are the **sensory organs** and are as follows:—

Olfactory organs.—Just within the nostrils are two little cavities occupied by the **olfactory sacs.** In these sacs the **olfactory nerves** are distributed, ending in delicate nerve cells, which are sensitive to odors; Fig. 96 *A*.

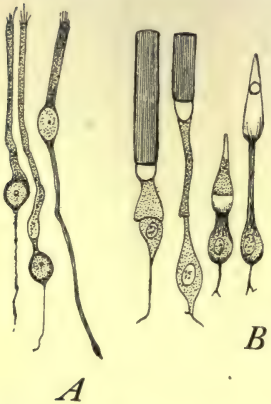

FIG. 96.—TERMINATION OF SENSORY NERVE CELLS

A, Olfactory cells; *B*, cells in the retina, sensitive to the light, showing the rods on the left and cones on the right. (Dogiel and Gaupp.)

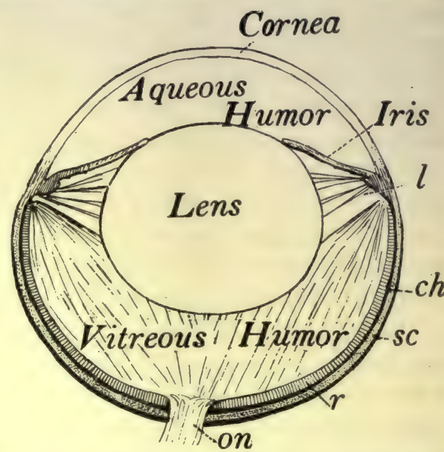

FIG. 97.—DIAGRAMMATIC CROSS SECTION OF THE EYE OF THE FROG

ch, choroid coat; *l*, the suspensory ligament; *on*, optic nerve; *r*, retina; *sc*, sclerotic coat. (Retzius.)

The eyes.—The eyes are large, spherical organs, planned after the structure of the vertebrate eyes in general. Figure 97 is a cross section of an eye showing the important parts. It is a spherical chamber, the walls of which are opaque, except in front, where they are transparent, and act like the dark chamber of a camera. The walls of the chamber are made of several layers. In the very front is the **cornea,** presenting a transparent curved surface. The back part, comprising about two-thirds of the chamber wall, is made of three layers. On the outside is a **sclerotic coat,** *sc*, composed of fibrous tissue and cartilage; next to this a thin coat containing pigment, the **choroid,** *ch*, and inside of this a still thinner **retina,** *r*, which

is the sensitive part of the eye. At the back of the chamber is an opening through which the **optic nerve** enters, *on*. After entering the eye the nerve spreads out on the retina, where it is affected by the light entering the eye. The chamber of the eye is divided into two parts by a large spherical, transparent, **crystalline lens,** held in position by several bands of fibers, shown at *l*. Anteriorly the lens is partly covered by an opaque membrane, really a continuation of the choroid, which grows out from the wall of the chamber on all sides. This is the **iris,** and it covers the outer part of the lens, except in the middle, where the lens is not covered. This opening is the **pupil,** and serves to allow light to enter. The iris contains pigment cells, which give the eye its color. Each of the two chambers of the eye is filled with a transparent fluid. That lying between the cornea and the lens is the **aqueous humor,** and that back of the lens, which is rather more solid, is the **vitreous humor.** The **retina,** which lines the eye chamber, is an extremely complicated organ, made of hundreds of thousands of end organs of sensitive nerves. It is a complex of neuron bodies, dendrites, and axons (Fig. 96 *B*), and is highly sensitive to the light, which is focused upon it by the lens. Attached to the ball of the eye are six muscles, by means of which it can be rotated in any direction.

The ears.—The frog has no external ears. Just back of the eyes are two rounded, flat depressions, each formed by a membrane which covers the real ear. If the thin skin which covers this area be removed, a rather tough, flat membrane will be found beneath, which is the **tympanic membrane** proper. This membrane extends over a shallow conical cavity, called the **tympanum** or **ear-drum.** This cavity connects below with the mouth through the **eustachian tube.** Extending across this is a slender bar of bone and cartilage, called the **columella.** This is attached to the membrane at one end and connected with the inner ear at the other, and transmits vibrations of the membrane to the inner ear, the real organ of hearing.

The **inner ear,** which is the true sensory end organ of the auditory nerve, lies embedded in the bones of the skull. Its general appearance may be seen from Figure 98. It is quite a complicated organ, and the auditory nerve enters in and finally terminates in delicate endings, which are readily stimulated by the vibrations brought from the exterior through the membrane and the columella. The canals shown at *c*, the **semicircular canals,** have a function related to balancing the body and keeping it in an upright position, *i. e.*, **equilibrium.**

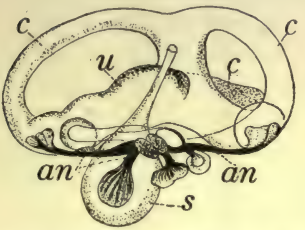

FIG. 98.—THE INTERNAL EAR OF THE FROG

an, auditory nerve; *s*, saccule; *c*, semicircular canals; *u*, utricle. (Retzius.)

Other senses.—The sense of *smell* is located in the nostrils. These openings lead into little **olfactory sacs** just within the bones, and the air which enters them passes through the bones into the mouth by openings on the roof of the mouth called **internal nares.** The olfactory nerve is expanded in the olfactory sac, where vapors that may be in the air affect it.

The sense of *taste* is situated on the tongue, within which are end organs sensitive to liquids. Only substances dissolved in liquids are capable of affecting these end organs; Fig. 99.

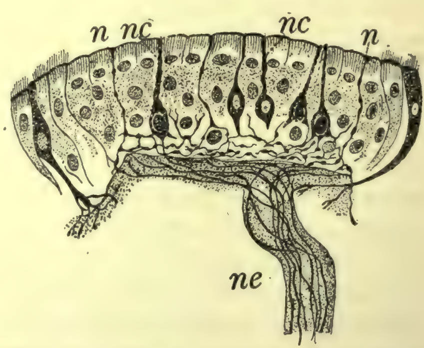

FIG. 99.—SECTION OF TONGUE OF FROG

n, nerve ending; *nc*, nerve cells; *ne*, nerve trunk. (Gaupp.)

The *touch* and *pressure* senses are located in the skin. Scattered over the body generally are numerous end organs, which

form the termination of the sensory nerves. They are of different kinds, and doubtless have different functions, but all are associated with what is in general called the sense of *feeling* or *touch.*

The Excretory Organs.—Lying in the back part of the abdomen near the legs are two flat, rather oval bodies, one on either side of the middle line, the **kidneys;** Fig. 92. Each is abundantly supplied with blood vessels, a fact which indicates important functions. Microscopic study shows them to be made of many coiled tubes, similar to the nephridia of the earthworm. These tubes remove excreted products from the blood which passes through them. From the outer side of each a small duct, the **ureter,** passes backward toward the cloaca, where it empties into the **bladder** (Fig. 90 *bl*), a rather large two-lobed sac, which may be filled with the urine secreted by the kidney, or may collapse when empty. It opens into the cloacal chamber, and its contents are discharged through the common cloacal opening. (In man a special duct, the *urethra,* leads from the bladder to the exterior.)

Reproductive Organs.—The two sexes in the frog are in separate individuals, thus differing from the condition found in the earthworm. The male may be distinguished externally by a thick pad on the under side of its thumb, which is rather large in the spring, but small at other seasons of the year. The **spermaries** are found in the male at the upper end of the kidneys; Fig. 92 *sp.* They are two in number, rounded or oval in shape, and of a light yellowish color. Attached to them are usually several branching masses of yellow **fat.** The **sperm** produced in the spermaries are carried through some delicate ducts into the kidney. These ducts, the **vasa efferentia,** pass through the kidneys and empty into the ureters, which lie on their outer edge. The ureters in the frog thus serve for the exit of both the kidney secretion and the secretions from the spermaries. These ureters are, in some species of frogs, enlarged into a small sac just at the point where they enter the cloacal chamber, and in these sacs the sperms are stored until

the frog is ready to discharge them at the time of copulation. These sacs are called **seminal vesicles.** Some species of frogs do not have such vesicles.

In the females the **ovaries** are situated in a position corresponding to that of the spermaries in the male; Fig. 100 *ov.* During the late spring and summer they are rather small, slightly folded, leaf-like organs, not much larger than the spermaries, though differing in shape. In the fall of the year the eggs in these ovaries begin to grow, causing the ovaries to become greatly expanded. During the fall the ovaries are usually greatly swollen and completely fill the abdominal cavity, almost concealing the other organs. The **oviducts** that carry the eggs to the exterior are not directly connected with the ovaries. They are very much coiled tubes, *o,* lying beside the kidneys, each ending at its anterior end in a funnel-shaped opening. From this opening the tube passes backward beside the kidneys, and, after making many coils, finally opens into the cloacal chamber at the back. Just before its termination it is swollen into a rather large, thin-walled chamber, the **uterus,** *ut,* in which the eggs may be stored for a time after passing through the oviducts before the final egg laying. These long ducts vary greatly in size at different seasons,

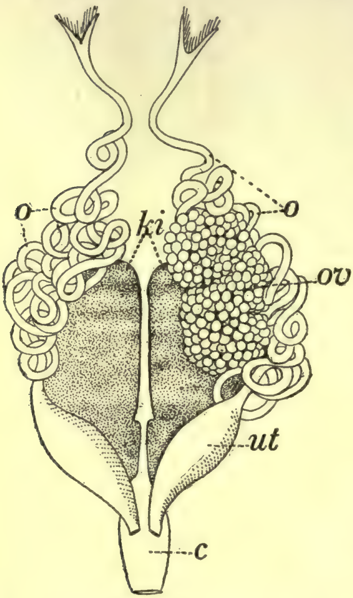

FIG. 100.—REPRODUCTIVE ORGANS OF A FEMALE FROG, ATTACHED TO THE KIDNEYS

ki, kidneys; *o,* oviduct; *ov,* ovary filled with eggs; *ut,* uterus; *c,* cloacal chamber.

being small in the summer, but enlarging with the enlargement of the ovaries, and swelling greatly in the early spring preparatory to egg laying. In the walls of the oviducts are numerous little glands, whose function is to secrete material around the egg to form the shell or other protective covering. They are **nidamental glands** (Lat. *nidus* = a nest).

It will be seen that the sexual organs and the kidneys are very closely connected. They lie close together, have a common opening, and in the male the same duct, the ureter, serves for the exit of the sperms and the urine. A similar close relation is found in other vertebrates, and a study of the development of the animals shows that their ducts are originally derived from the same organ in the embryo. The two systems together are known as the **urogenital system.** In the frog this system opens to the exterior with the intestine by the single common cloacal opening. In higher animals they may have separate openings.

LABORATORY WORK UPON THE FROG

For a detailed dissection of the frog, reference must be made to some of the numerous laboratory manuals. The brief general directions given below will be sufficient to illustrate the topics discussed in the text, and at least this amount of laboratory work is necessary to make the text properly intelligible.

If the specimens are obtained alive they should first be killed with chloroform, and, while still fresh, all of the points in the external anatomy should be made out. Note should be made of the following: head; body; absence of tail; the loose skin, attached, however, at certain points; arms; numbers of fingers; legs; number of toes; web between the toes; mouth; nostrils; eyes with eyelids; ears; cloacal opening. Open the mouth and note tongue; glottis; gullet.

The dissection of the organs of the abdomen can best be made with a freshly killed specimen, but it may be done satisfactorily with animals preserved in alcohol or formalin. The dissection of the brain and spinal cord should always be made upon animals preserved in alcohol, since these organs are too soft to handle in fresh specimens. A mounted skeleton of the animal should be at hand for study and comparison with the animal under dissection.

The order of dissection given below is so planned as to make it possible to do practically all of the dissection upon a single specimen. The specimen may be preserved in formalin and the work carried out at leisure. If the order given is followed, it is possible to have a large class working at the same time, and, when the work is finished, all of the important parts in the anatomy will have been made out, except the skull and the shoulder girdle, these having of necessity been destroyed in opening the body and in exposing the brain. If frequent references are made to the description of the frog given in the text, the brief description here given will be sufficient to make a satisfactory dissection.

Open the frog by a median ventral incision, made with scissors, extending from the legs forward to the sternum, cutting through both skin and flesh. The blunt end of the scissors is then to be thrust under the sternum, and this girdle of bones is to be cut through. This will make it possible to open the abdomen, pinning out the flaps of the abdominal walls and the arms so as to expose the organs of the abdomen. If the frog is a freshly killed specimen, all of the subsequent study of the viscera should be made with the animal immersed in water. If the frog is a preserved specimen, this is not so necessary.

The organs of the abdomen may now be studied. The following parts should be made out without any further dissection, being disclosed simply by pushing the organs one after the other to one side, and they may be examined conveniently in the following order: liver; heart; large arteries around the heart; veins entering the heart; stomach; intestine; gall bladder; rectum; mesentery, which contains blood vessels that may be traced to the liver.

In opening the body, if the specimen is a fresh one, there is danger that some of the blood vessels may be cut, making it difficult or impossible to follow the blood vessels. In order to work out the blood vessels satisfactorily, it is necessary to have an injected specimen. These may be bought of dealers in natural history supplies, or the injection may be done by the instructor.

If the specimen is a female, the body cavity will, at certain seasons of the year, be filled with an enormously expanded ovary, filled with eggs. In order to make out the other abdominal organs, these must be removed carefully, so as not to injure the other parts. After they have been removed there will appear lying on either side of the back part of the abdomen the very much enlarged oviduct, showing as a much coiled tube. This should also be removed, note being made of its connection with the cloacal chamber behind. If the ovary is not thus enlarged, or if the specimen is a male, it is not necessary to remove the reproductive organs to show the other features.

With the organs all in position, now make out the rectum; the bladder; the spleen; the cloacal chamber; the kidneys; the spermaries; the ovaries and oviduct in the female, and the spermaries and vas deferens in the male.

Remove the heart, liver, stomach, and intestines. This will disclose the lungs; the two systemic arteries uniting to form the dorsal aorta, which should be traced to where it divides to supply the legs; the nerves to the arms; nerves to the back; three large nerves arising from the backbone and extending toward the legs, and finally uniting to form the sciatic plexus, from which arise the large nerves entering the leg. By lifting up the aorta gently, delicate branches of the sympathetic system may be seen and traced to their ganglia.

One leg of the animal should be dissected to make out the muscles, nerves, bones, and joints. The muscles should be separated from each other and traced to their origin and insertion, special notice being taken of the long tendons extending from the lower muscles down to the toes. In the joints, note the freedom of motion of the bones; the tendons, which extend over them; the rather loose ligaments that unite the bones; the readiness with which the bones come apart when the ligaments are cut; the smooth surfaces of the ends of the bones; and the cartilage that covers their ends. (If there is time for more careful dissection, reference must be made to laboratory guides on the dissection of the frog.) Clean all of the soft parts from the bones of the leg, separating and identifying each bone.

Examine the eyelids; the iris; the pupil. Make an incision through the iris and remove the lens; note the cavity of the eye behind the lens. Cut an incision through the tympanic membrane, noting the shallow cavity beneath it, the tympanic cavity, the bony columella extending across it to the skull. A bristle thrust into the bottom of this cavity will enter the mouth through the eustachian tube.

Remove with a knife a bit of the flat bone on top of the skull, exposing the brain; and then, with forceps and scissors, break away the bone so as to expose completely the brain and spinal cord down the back to the urostyle, taking care not to injure the soft parts. Identify all parts of the brain as described on page 193.

The skeleton should be studied from another specimen. Remove all the soft parts from the skeleton, separating all the bones. Clean and identify each (Fig. 88), and compare with the mounted skeleton.

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CHAPTER X

THE PHYSIOLOGY OF AN ANIMAL

HAVING now studied the structure of multicellular animals, we will consider briefly the functions of the various organs, with special reference to the frog.

Alimentary System.—The primary purpose of the alimentary canal is the digestion and absorption of food. The food of animals is always organic, since animals are unable to utilize mineral substances upon which plants subsist. Animals feed upon the substances manufactured by plants: starch, the first product of photosynthesis, may serve animals for food, and the same is true of sugar, fats, and proteids. These foods are usually in a solid form when taken into the animal's mouth, and in order to be of any use they must pass from the alimentary canal into the blood vessels. Solid food is incapable of passing through the intestinal walls, and must be changed so that it can be dissolved in the liquids of the alimentary canal, a process called **digestion.** Digestion is brought about by **digestive fluids** which are secreted by **digestive glands** within the alimentary tract. The frog has no **salivary glands** such as man possesses, and the first digestive glands are in the walls of the stomach. These are microscopic in size and are called **gastric glands.** They are present in large numbers and secrete the **gastric juice,** which is poured directly upon the food after it reaches the stomach. A second digestive gland is the **pancreas,** lying just below the stomach and pouring its secretion, the **pancreatic juice,** by a special duct into the intestine, close to the stomach. This is mixed with the food just as it leaves the stomach and after it has been acted upon by the gastric juice. By the action of these two digestive fluids the solid foods are changed in their nature and rendered partly soluble. They are then dissolved in the intestinal liquids, becoming a thick, rather slimy mass of dissolved material. The different foods eaten by the animal are subject to different

changes under the influence of the separate digestive fluids, those secreted by the stomach producing a different kind of digestion from those of the pancreas; but all aid in rendering the food soluble.

Absorption.—The food is driven through the alimentary canal by the muscular contractions of its walls. These muscles are in two sets, one extending lengthwise and the other running around the intestine in a circular direction. By their contraction waves of constriction pass along the intestine, forcing the food slowly along. This peculiar writhing motion of the intestine is spoken of as **peristalsis** (Gr. *peri* = around + *stalsis* = a compression).

As the food is pushed through the intestine its digestion and solution is completed and it begins to pass through the walls of the intestine into the surrounding blood vessels. As the intestinal contents pass onward more and more of the nutriment contained in the food is absorbed from it and enters the blood. The undigested and useless portions of the food pass on and eventually, in the form of fæces, are voided through the cloacal opening.

Circulation.—The food absorbed into the blood is now carried over the body in the blood. The liquid part of the blood, the **plasma,** is the circulating medium, the red and white corpuscles having special functions. The **red corpuscles** (*erythrocytes*), which are by far the most numerous, give the blood its red color and are associated with respiration. The **white corpuscles** (*leucocytes*), of which there are several kinds, have various functions, one of which is the removing of foreign bodies from the body and protecting it from the attacks of microscopic germs, or other irritating substances that may enter the tissues. The white corpuscles with this power are called **phagocytes** (Gr. *phagein* = to eat + *cytos*); they are able to leave the blood vessels, by forcing their way through the walls of the capillaries; Fig. 101 *leu.* They then migrate among the tissues and collect at any part of the body to guard it from an attack.

The blood is kept circulating through the vessels by means of

the **heart,** which acts as a pump. In the frog's heart there are three chambers and the circulation is as follows: The blood which enters the heart from the body, which is *impure* blood, is received first into the **venus sinus** (Fig. 92 *B*, *vs*), and from here it enters the **right auricle;** Fig. 102 *ra*. At the same time pure blood enters from the lungs and skin, and is received in the left auricle. Now the two auricles contract and force the blood into the single ventricle *v*, through the openings indicated by the arrows in Figure 102. The ventricle thus receives both pure and impure blood, the pure blood being poured into its left side and the impure blood into its right side. These two kinds of blood are partly mixed, except for a fraction of a second, when they are separate from each other. They are kept from mixing too quickly by several muscular bands stretching from the walls of the heart. But almost at the same instant that the ventricle is filled it contracts, and its contained blood is forced into the large artery, the **bulbus arteriosus.** This artery, as will be seen from Figure 102 *ba*, opens on the right side of the ventricle and consequently will receive first the blood which entered the ventricle from the right auricle, which is impure blood. Thus impure blood passes first into the arteries, to be followed by mixed blood and finally by the purer blood that comes from the left side of the ventricle, and hence from the left auricle. With each contraction of the heart there enters the arteries first a little impure blood, then a little mixed blood, and finally a little pure blood.

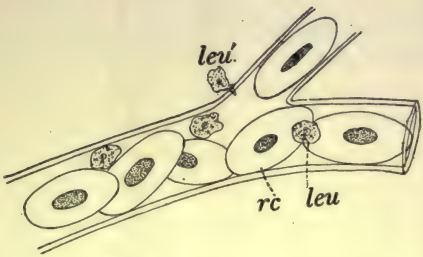

FIG. 101.—A SINGLE CAPILLARY

Showing the corpuscles being forced through its walls.

rc, red corpuscles;
leu, leucocytes;
leú, a leucocyte that is forcing its way through the walls of the capillary into the surrounding tissues.

From Figure 102 *pu*, it will be seen that the first branch of the artery passes to the lungs. In the bulbus arteriosus are valves so arranged that the first blood passing from the heart with each beat goes to the lungs; after these are partly filled the next blood passes through the blood vessels shown at *ao*, down to the arms and to the lower parts of the body; and finally the last of the blood that comes out with each beat of the heart passes up into the head through the artery, *co*. Thus the most impure blood passes to the lungs, where it is purified, the mixed blood goes to the lower parts of the body, and the purest blood goes to the head and brain. The separation of pure and impure blood in the frog is not complete, but the arrangement just described is such as to send the most impure blood to the organs which purify it, and the purest blood to the brain where the purest blood is needed. The two auricles are separated from the ventricle by valves, *va*, opening mechanically in one direction, in such a way that when the heart beats the blood is forced onward and never backward.

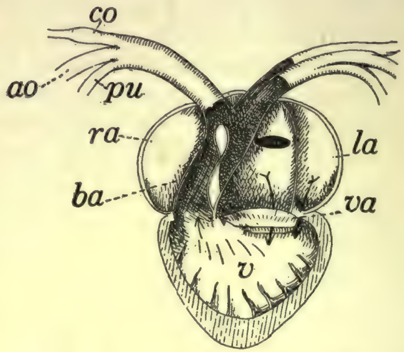

FIG. 102.—A DIAGRAM OF THE HEART OF THE FROG TO EXPLAIN ITS CIRCULATION

ao, aorta, passing to the posterior part of the body;
ba, bulbus arteriosus;
co, carotid artery going to the head;
la, left auricle;
pu, pulmonary artery passing to the lung;
ra, right auricle;
v, ventricle;
va, valves separating auricles and ventricle. The arrows show the passage from the auricles to the ventricle.

(Modified from Parker and Haswell.)

The blood passes out through the arteries and is carried by the numerous branches into the various parts of the body, the small branches breaking up finally into minute twigs called **capillaries**, that are distributed in great abundance in every active organ.

While passing through these capillaries, the food materials, absorbed by the blood from the alimentary canal, and the gas absorbed from the lungs, pass from the blood into the tissues where they are needed. In this way the food and oxygen are supplied to the active tissues of the body. At the same time waste products, which have been produced in the active tissues, are returned to the blood, so that the blood, after passing through the capillaries, goes back to the heart as impure blood. After reaching the heart the impure blood goes to the lungs, where part of its impurities are passed off into the air.

Lymph System.—A part of the circulatory system is called the lymph system. As the blood is flowing in the capillaries some of the liquid plasma soaks through the walls of the capillaries out into the tissues. When it reaches the tissues it is no longer called blood but lymph, and is a colorless clear liquid which bathes every living cell. This lymph contains, dissolved in it, the nutriment absorbed from the intestine; and, since it now actually bathes the living cells, these can take from it directly the nourishment they need for their activities. Into this lymph the living cells also excrete all the waste products that have resulted from their life processes, the lymph receiving all the wastes of the body. The gases, which comprise part of this waste, pass at once into the blood by diffusion; but the other materials remain dissolved in the lymph and finally reach the blood by the following course: The lymph gradually collects in tiny spaces, **lacunæ,** scattered over the body, and from these flows into little vessels connecting with each other, called **lymph vessels.** These small vessels unite together to form larger ones and the larger vessels finally empty into the veins. The vessels around the front end of the body converge to two minute sacs lying deeply imbedded near the third vertebra; and the vessels in the hind part of the body converge into similar sacs situated over the hips, near the lower end of the urostyle. These four sacs have muscular walls and pulsate, and are called **lymph hearts.** When they beat they force the lymph into the veins

which lie near them and with which they are connected. In this way the lymph, which originally came from the blood plasma by dialyzing through the walls of the capillaries, returns into the blood; thus all the secreted products from the living cells pass into the blood, either directly as in the case of gases, or indirectly by passing first into the lymph and then emptying with the lymph into the blood vessels.

Note.—A similar lymphatic system is found in all higher animals, but its course is different from that in the frog. In man, for example, the lymph rises by diffusion through the capillaries, and collects in lacunæ and lymph vessels in a similar manner. But there are no lymph hearts. The lymph vessels unite to form quite large vessels, and all eventually empty into the large veins in the neck. There are two chief trunks of these vessels, one bringing the lymph from the upper parts of the body and emptying into the right jugular vein, and the other, a much larger one, bringing the lymph from the lower parts of the body and from the alimentary canal and flowing up through the thorax, to empty finally in the left jugular vein. This latter lymph vessel is called the **thoracic duct.**

Respiration.—The impure blood from the heart passes through the pulmonary artery to the lungs (Fig. 92), a part of it going into a small branch, the **cutaneous,** *cu,* which carries it to the skin. The lungs are air sacs connected with the mouth. Just back of the tongue we have already noticed the glottis, which is a slit leading into a small cavity holding the **vocal cords,** whose vibrations cause the various sounds produced by the animal. This cavity is the **larynx** and it lies just under the throat. At its inner end it opens at once into the lungs, since the frog has no windpipe (**trachea**) such as is found in animals with long necks, like man. The air enters the lungs through the larynx and, filling them, comes in close contact with the blood, which is distributed in finely divided capillaries in their walls. The blood that goes to the skin through the cutaneous artery is distributed in fine capillaries and brought into close contact with the oxygen which is dissolved in the water in which the animal lives.

The **hæmoglobin,** which gives the red color to the red cor-

puscles, absorbs large quantities of oxygen as the blood is flowing through the lungs and skin. The oxygenated blood then passes from the lungs back to the heart and is pumped out through arteries to the tissues. Here the red blood corpuscles give up their oxygen, and at the same time the blood absorbs carbon dioxid (CO_2) from the tissues. When the blood, therefore, leaves the capillaries on its journey back to the heart, it has left behind its oxygen and taken in its place carbon dioxid, which it gives up when it next reaches the lungs or the skin, at the same time taking up oxygen. The process of respiration is therefore a system of *gas exchange.*

Metabolism.—In the living tissues the food and oxygen are chemically combined, an **oxidation** of the food taking place. The chemical changes that occur are numerous and result in the formation of new materials for the body, producing growth, development of muscular activity, and all of the other phenomena of life, and finally resulting in the appearance of waste products. The waste products are chiefly three: (1) a *gas,* carbon dioxid (CO_2); (2) a *liquid,* water (H_2O); (3) a *solid,* called **urea** (CON_2H_4), which contains the nitrogen. Although the urea is solid under all ordinary conditions, it is dissolved in the liquids of the body, since it is soluble in water, and is therefore in a state of solution while in the body. These three waste products are not only valueless but distinctly harmful, and it is necessary for the body to get rid of them. The series of chemical changes which finally results in waste products is called **metabolism.**

Excretions.—The elimination of the waste products of metabolism is known as **excretion.** The carbon dioxid gas passes into the blood, and when the blood reaches the lungs the gas diffuses from the blood into the air. The waste water also passes into the blood and is passed off from the body through the kidneys, the lungs, and the skin. The urea finds its way into the blood, and as the blood flows through the kidneys (Fig. 92), they take the urea from it. They then pass it through their ducts dissolved in the **urine,** and it goes to the bladder and

then passes to the exterior with the fæces, the one cloacal opening serving, in the frog, for the exit of undigested food as well as for the urine.

Support.—The skeleton serves to support the softer part of the body.

Motion.—The motion of the frog is accomplished by the muscles. The muscles are numerous, and each has its own special attachment to the bones; Fig. 89. Every muscle possesses the power of shortening, but has no other function; and the ordinary muscles are attached to two bones in such a way that when the muscle shortens one bone is moved upon another. All the motions of the body are produced by the shortening of the different muscles. Many of the muscles are in pairs, one of each pair serving to bend a joint, the **flexor,** and the other straightening it, the **extensor.** The details of their actions we cannot consider here, but it will readily be seen that with the many muscles present in the frog's body a great variety of motions can be produced. The selection of the proper muscles to produce any desired motion is a complicated process, some motions indeed requiring the orderly selection of a large number of muscles, which must act together in perfect harmony. This power of selecting the muscles and causing them to act in unison and in harmony with each other is called **coördination.**

The Coördinating System.—The nervous system of the frog controls all other functions. As already seen, it consists of (1) a *central system*, the **brain** and **spinal cord**; (2) the *peripheral system*, the latter composed of the **nerves** distributed over the body, and the various *end organs* of the nerves. The central system is really the center of activity, and the nerve fibers are merely paths for conducting impulses from one part of the body to another. Some of the end organs at the outer ends of the nerves receive impulses from the brain; others receive them from the exterior and transmit them to the nerves to be carried to the brain. The brain corresponds to the central station of a telephone system, which is connected with all parts of the city by wires hav

ing at their ends the individual telephones which may receive communications from the central system or send messages to it. So the central nervous system contains the intelligent, originating force, and being in communication with every part of the body, controls all of the functions in such a way that they act in harmony. This central system has a series of **efferent nerves,** by which it sends messages outward, and a series of **afferent nerves,** by which messages are brought inward to the brain. The most important of the latter are the **sensory nerves.**

Sense organs.—Each sensory nerve ends in a sense organ, so formed that it is excited by definite external stimuli. One of them, the ear, is stimulated by vibrations of the air; another, the eye, by vibrations of ether; others by a slight pressure or touch; others by heat; others again, by chemical substances, producing taste; and others by vapors in the form of gases, causing the sense of smell. Figure 96 shows the microscopic structure of some of these sensory end organs. In each case the end organ is started into activity by an external stimulus, and when thus excited an impulse starts from it over the nerve fiber and passes to the central part of the nervous system. In the central system, the stimulus produces what we call a **sensation,** and this gives the brain a knowledge of what is going on at the outer end of the nerve. *Sensation never occurs until the impulse reaches the brain.* From these sensations the brain obtains information as to what is going on in different parts of the body, and upon this information, bases its knowledge and regulates the activities of the body.

Reflexes.—The nervous system is made up of a mass of neurons whose connections with each other are inconceivably complex. These neurons, with their long axons, unite in harmonious activity the different organs of the body, and they do this by virtue of the fact that their axons, though distributed all over the body, all converge in the central system, where they can be associated together by the numerous neuron bodies that compose these central ganglia; Fig. 85. The courses taken by

these impulses after reaching the centers are complex in the extreme, and quite beyond our power to follow. They are accompanied by sensations and by whatever of **consciousness** the animal possesses, and they control the life and motions of the animal. The simplest of these connections may produce motion without any consciousness on the part of the animal. This is shown diagrammatically in Figure 103. Some external stimulus excites one of the sense organs in the skin, *s*, and starts an impulse in the nerve fiber, which then travels quickly through the axon to its inner end, *c*, in the cord. The impulse then passes out of the axon through the arborizations, at *c*, to the neighboring dendrites of other neurons. These neurons may be **motor cells,** *m*, by which is meant that their axons, *e*, extend outward and terminate in muscle fibers, as at *mu*. Hence the impulse that enters them, after passing out over the axon, eventually reaches a muscle fiber, and causes the muscle to contract. Such an action may take place without the impulse going to the brain, and would therefore not involve any consciousness or any sensation, for these latter functions occur in the brain only. Hence the animal might move if touched by an irritating object, without any

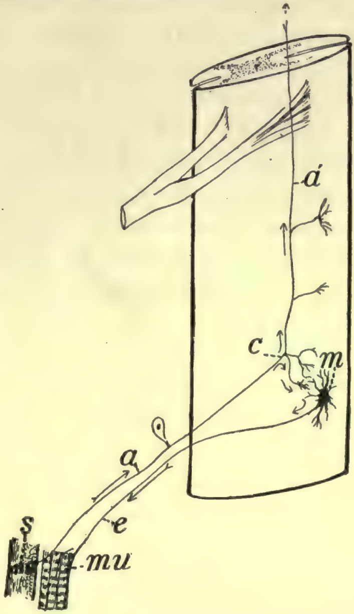

FIG. 103.—A DIAGRAM ILLUSTRATING A REFLEX ACTION

An impulse that starts from the sense organs in the skin, *s*, passes to the spinal cord through the afferent nerve, *a*. Upon reaching the center, at *c*, the impulse may pass over to the motor cell, *m*, from whence it passes downward through the efferent nerve, *e*, to the muscle fibers, *mu*. Part of the impulse from the *c* may pass up through the fiber, *á*, to the brain and produce sensation.

necessary consciousness on its part, as actually happens in sleep, for example. Such an action is called a **reflex act,** a name derived from the idea formerly held that the impulse starting from the sense organ was simply reflected back after reaching the cord. Although we know to-day that the impulse is not simply reflected back, but is profoundly modified in the cord, the name reflex is still retained for this type of reaction.

Although a reflex act is not necessarily accompanied by consciousness or sensation, this is not always the case. From the diagram (Fig. 103), it is evident that the impulse, on its arrival in the cord, may not all pass into the motor nerve cell, but some of it may pass up through the fiber, *á*, toward the brain, and this part of the impulse, when it reaches the brain, will give rise to a sensation. The action that follows might still be the reflex, or it might be a truly voluntary one, *started by the brain* as the result of the sensation. Reflexes play a very large part in the life of all animals. Even in our own life many of our actions are thus reflexly performed without any special volition.

Reproduction.—The eggs of the frog are only developed at certain seasons of the year. Late in the spring and early in the summer the ovaries are small, but toward the end of summer and in the fall the eggs begin to develop and cause the ovaries to expand until they almost fill the body cavity. When the frog goes into the dormant condition of **hibernation** (Lat. *hibernare* = to pass the winter), the female is usually greatly distended with the swollen ovary, and in this condition the winter period is passed. The oviducts have also enlarged and elongated, and remain so during the winter, while the animal is buried under ground. With the opening of the spring the frog emerges and resumes its active life, and in a few weeks reaches what is called the **breeding season,** which means the season for the discharge of the sexual products. As this season approaches the eggs break out of the ovary and fall into the abdominal cavity. The funnel-shaped opening of each oviduct is provided with vibratile cilia (Fig. 100), and, probably by

their action, the eggs are swept into the opening, and then slowly pass down through the coils of the oviduct toward the uterus. As they pass along they are covered with a gelatinous substance, which is secreted from the glands in the walls of the ducts and forms a layer around the eggs. When the eggs reach the uterus they are stored there for a time until the animal is ready to lay her eggs.

With the approach of the breeding season the spermaries of the male also become very active and secrete sperm fluid. This passes down the ducts to be stored in the seminal vesicles, where it remains until the period of copulation.

At the breeding season the male frog fastens himself to the female, who is about to lay her eggs, and remains firmly attached to her until she lays them, remaining thus attached for days or even for weeks in some cases (*copulation*). After the eggs are laid the male leaves the female and pays no further attention to her. When the eggs are laid they are rather slowly passed from the body by the cloacal opening, and at the same time the male ejects the sperm fluid from his body over them. The sperms themselves penetrate the jelly and eventually enter the eggs, producing fertilization. After the eggs are thus laid the ovaries and the oviducts contract and in a short time shrivel to a size much smaller than that which they had at the breeding season. This diminished size continues until late in the summer, when the ovaries begin to increase in size again with the growth of the ova, in preparation for the next breeding season.

The eggs of the common frog are always laid in water and at first form a rather small mass of eggs with their surrounding jelly. But the jelly quickly absorbs the water and swells to many times its original size, inclosing each egg in a thick layer. This jelly appears to have two purposes. It is a protection to the eggs from the attack of birds and perhaps other enemies. It seems also to have the power of absorbing the sun's rays and holding them back from too great radiation, the result being that the egg is kept warmer than it would be without the jelly. This

hastens the development, since its rate is dependent on temperature. Our common frog lays its eggs in irregular masses, which may be found in abundance in the spring months around pools of fresh water. The toad has somewhat similar breeding habits, but lays its eggs in long strings. Inside the jelly the fertilization of the eggs is completed and the development begins, and here the young remain until they are ready to hatch as young larvæ.

PHYSIOLOGY OF THE EARTHWORM

The organs of the earthworm are much simpler than those of the frog. Some of the systems of organs found in the frog are apparently absent in the earthworm. There are, for example, no lungs nor other special organs devoted to respiration; there is neither heart nor system of bones for support. But although some of these systems of organs appear to be absent, their functions are not lacking. In other words, the earthworm has exactly the same functions of life as the frog, but carries them out in a simpler way. Respiration is carried on through the skin; the motions of the animals are confined to a writhing motion made by the muscles of the body wall; the circulation of the blood is produced by the contraction of the blood vessels instead of by a heart; excretions are carried on through the skin and also by the nephridia. In short, the earthworm has the same general functions as the frog, only they are carried out on a simpler scale and by a simpler series of organs. Since its organs are simpler, we speak of the earthworm as having a *lower organization* than the frog.

CHAPTER XI

THE DIFFERENCES BETWEEN ANIMALS AND PLANTS: THE MUTUAL RELATIONS OF ORGANISMS

THE DIFFERENCES BETWEEN ANIMALS AND PLANTS

If we confine our attention to the larger organisms, the differences between plants and animals are very evident; but when we turn our attention to some of the lower members of each group, the differences are less evident and most of them disappear. A castor bean and a frog are very unlike, but *Peranema* and *Euglena* (Fig. 29) are so similar that it is hardly possible to say whether either of them is an animal or a plant.

In their life functions, too, the higher plants and animals differ widely. Most of the general functions of animal life are possessed in a modified form by plants also; but since some functions are possessed by animals alone, a division of functions into two categories is frequently adopted.

Vegetative functions are those possessed by both animals and plants. They are chiefly associated with food and growth, and are: *alimentation*, *circulation*, *respiration*, *excretion*, and *reproduction*.

Animal functions are those possessed by animals and not by plants. They are *motion* and *coördination*.

Both animals and plants have vegetative functions, but they are carried on quite differently in the two groups, resulting in a radically different type of life in animals and plants. The study already made of the biology of organisms enables us now to ask intelligently, What is the difference between animals and plants? Although it is fairly easy to see the difference between a tree and a dog, when we come to extend the comparison to smaller and lower organisms it becomes more and more difficult to determine any distinc-

tions between the two kingdoms. Indeed, when we analyze the subject to its limit, we find it impossible to draw any sharp line separating animals and plants, for there are some living things which show so few characteristics of either kingdom that we cannot determine with accuracy whether they belong to one group or the other. It is possible, however, to draw a general distinction between the two, and from this general distinction we can derive certain other secondary differences, which are more evident.

The Fundamental Distinction.— The primary distinction between animals and plants is in the process of photosynthesis. The plant kingdom alone has the power of utilizing the rays of the sun and manufacturing starch out of carbon dioxid and water: animals never have this power. From this primary distinction arise several other minor points of difference, more or less sharply separating these two groups.

Secondary Differences.— *A*. **Color.**— Plants which have the power of photosynthesis are provided with the green coloring matter, chlorophyll. Animals, on the other hand, are not provided with this coloring matter.

B. **Motion.**— Since animals live upon solid foods, they have to search for it, and they are, as a rule, provided with motion. Plants, on the other hand, having no need to search for their food, since they find it in the atmosphere and soil, have not, as a rule, developed the power of motion.

The various methods of motion developed by animals may be summarized as follows: (1) **Amœboid movement,** as found in *Amœba*, by means of lobes of the living protoplasm. It is confined to unicellular organisms. (2) **Ciliated** and **flagellated motion,** produced by vibratile, hairlike processes of the protoplasm. Cilia are moderately short processes, and where found are usually present in large numbers. They are found in many unicellular animals and also in multicellular forms. Even the highest animals have cilia on the cells lining the air passages and various other ducts. Flagella are longer than

cilia, and occur only in small numbers on any cell, one or two being the usual number. Higher animals do not have true flagella, except in their sperms; see page 250. (3) **Muscular Movements.**—In all animals above the unicellular forms certain cells, or parts of cells, become specially modified for contraction, thus becoming muscles. These develop into a system which produces the many types of locomotion possessed by animals.

While plants as a rule are stationary, a few of them possess independent motion. Spores of many plants possess flagella or cilia; some of the lowest show amœboid motion, and some have methods of motion not yet understood, like *Diatoms* and *Oscillaria;* Fig. 68. Among higher plants movements of different parts of the leaves, stamens, etc., are not uncommon. No muscles are developed, however, in plants, the motions being due to slow changes in the protoplasm, which are not well understood. An independent locomotion is unknown among any plants except those of the lowest orders.

C. **Sensitiveness.**— In order to distinguish their food, animals have developed sensitiveness and sensations. Plants not needing to distinguish food so accurately have not developed much sensitiveness.

D. **Structure.**— As a rule animals have their bodies condensed into a small compass, and are provided with an opening for taking in food,— the mouth,— which is connected with a digestive system. Typical plants, since they feed upon gases and water, which are distributed everywhere, have their bodies widely expanded into branches, leaves, and root hairs, in order to come in contact with a large amount of air and soil. They never have any mouths, since they do not take solid food, and consequently have no digestive system.

The Income and Outgo of Animals and Plants.— An animal has an **income** as follows: —

Proteids, obtained from animal or vegetable food, but all originally derived from green plants.

Hydrocarbons (fats), derived from both animal and vegetable food.

Carbohydrates, derived chiefly from vegetable foods.

Water.

Oxygen, taken from the air by the respiratory organs into the blood.

Salts, of various kinds in the foods.

The **outgo of an animal** consists of: —

Carbon dioxid, excreted from the respiratory organs.

Water, excreted from the skin, kidneys, and some other organs.

Urea, excreted by the kidneys or their equivalents.

Proteids, eliminated in the reproductive bodies.

Salts, in various excretions.

After an animal has reached its full growth, the income and the outgo practically balance. With some animals this period of equilibrium lasts a long time, perhaps for years. With others, growth may continue until death comes, in which case there is never any period of actual balance.

The **income of a plant** consists of: —

Carbon dioxid, from the air.

Water, from the soil.

Minerals, from the soil.

The **outgo of a plant** consists of: —

Oxygen, from the leaves.

Water, from the leaves.

Carbon dioxid, from the leaves and other parts.

Proteids and various other substances, eliminated with dead leaves, branches, seeds, and other reproductive bodies.

No Sharp Distinction between Animals and Plants.—The criteria above given are ordinarily sufficient to distinguish between animals and plants, and will separate typical forms;

but when we come to consider low types, some or all of these distinctions disappear. There are, for example, many plants which have no chlorophyll (molds, toadstools, etc.), and hence have no power of photosynthesis; but they are, nevertheless, clearly plants, for no one would for an instant think of confusing them with animals, even though they do not contain chlorophyll. Some plants have independent motion, while some animals are stationary. Some plants are sensitive. The distinction of shape applies only to the higher organisms; for among the microscopic forms no distinction can be seen between the shape of animals and plants, some animals having no mouth, and some plants, as well as animals, having their bodies condensed rather than expanded. Thus it appears that each of the distinguishing characters separating animals and plants breaks down when we come to apply it closely to some of the low forms of life; until we have to admit that there is no absolute criterion separating the two kingdoms.

Nevertheless, there is rarely any real difficulty in making the distinction. It is true that there is a difference of opinion as to whether a few of the very low forms should be called animals or plants; but when we take all of the above facts into consideration, it is only in a few instances that we are unable to say positively that any given organism is either animal or plant. Most of the difficulty is confined to the microscopic forms which are among the lowest organisms, and the fact that among these there is no absolutely fixed line between the two kingdoms is of special significance as suggesting the origin of the two kingdoms from a common starting point by a process of evolution.

Organisms which possess chlorophyll, and consequently nourish themselves by photosynthesis, are sometimes said to be **holophytic** (Gr. *holos* = whole + *phyton* = plant). In contradistinction, organisms which have no chlorophyll and must depend upon others for sustenance are called **holozoic** (Gr. *zoon* = animal). Animals are practically all holozoic, and green plants

holophytic; but many plants are holozoic, a condition which is true of all *Fungi*.

Protozoa and Protophyta.— Both plants and animals may be found among unicellular organisms, the unicellular animals being known as **PROTOZOA** (Gr. *protos* = first + *zoon* = animal), and unicellular plants as **PROTOPHYTA** (Gr. *phyton* = plant); see Chapter III. Among such organisms there is sometimes a difficulty in distinguishing between animals and plants, since any structure of a distinctive character is lacking. Even here, however, the majority of forms group themselves in one of the two kingdoms, so that they can readily be separated. There are, however, a few forms which prove a puzzle. *Euglena* (Fig. 29 *B*), for example, has green chlorophyll, and is thus allied to the vegetable kingdom (*holophytic*); but it has also the power of motion, a mouth, and a red eye-spot. *Peranema* (Fig. 29 *A*), however, which is clearly allied to *Euglena*, has no chlorophyll and no plant characters (*holozoic*). We may, with equal justice, call both animals or both plants, or perhaps one an animal and one a plant. The bacteria (Figs. 33–35) represent another group which has been difficult to classify clearly; and for many years after they were first studied there was a considerable difference of opinion as to where they belonged. They have a method of life much like that of animals, but their general structure, their multiplication, their division to form long chains, and an occasional formation of spores, are points much more like plants, especially the *Fungi*. Continued study of the organisms has finally led to the conclusion that bacteria must be regarded as plants rather than animals, associated with the group of *Fungi*, and considered as resembling yeast and molds.

A few such organisms as these are the only ones that present much difficulty in distinguishing between animals and plants, and even these can be called animals or plants with a considerable degree of certainty. While no sharp line can be drawn, the difficulty of separating them is really not very great, and even among unicellular forms it is rare that we cannot deter-

mine satisfactorily whether to call an organism an animal or a plant.

Metazoa and Metaphyta.— With the multiplication of cells and their differentiation we find that the distinction between animal and plant at once becomes marked, until there is no longer any similarity between them. Indeed, in all organisms above the Protozoa and the Protophyta, the two kingdoms are sharply separated, all multicellular organisms being either so distinctly like plants or like animals that the difficulty of distinguishing them disappears entirely. From this point up, plants usually not only possess chlorophyll, but also show a general structure which indicates that they are adapted for the absorption of gases from the air, of water from the soil, and for the purpose of carrying on the process of photosynthesis; while animals have a structure of body adapted for taking only solid or liquid food. The difference in the shape of the animal and plant body becomes so well marked that there is no longer any confusion between them. Even though we find large

FIG. 104.—*DROSERA*, A CARNIVOROUS PLANT

Small insects are captured by the hairs on the leaves, digested, and, in a measure, assimilated by the plant.

groups of plants that have quite lost their chlorophyll (toadstools, molds, etc.), there is no longer any difficulty in determining that they are to be grouped with plants rather than with animals, in spite of their not having any green coloring matter. When, too, we find a plant like the sundew (Fig. 104), which captures insects by means of the hairs on its leaves, and digests and assimilates them, we call it a "carnivorous plant" (Lat. *caro* (*carnis*) = flesh + *vorare* = to eat), but do not confound it with animals. The **Metazoa** (Gr. *meta* = after + *zoon* = animal) and **Metaphyta** (Gr. *phyton* = plant) are sharply distinct.

CONTRAST BETWEEN THE ACTIVITIES OF ANIMALS AND PLANTS

The similarities and differences between animals and plants may be better understood if their properties are contrasted with each other in regular order. The following contrasts illustrate the distinction between these two groups: —

1. *Alimentation.*— In *animals* this system consists of a mouth, stomach, intestine, and digestive glands; food is taken into the body either as a solid or a liquid. In *plants* the system is poorly developed, consisting of root hairs for taking in liquids, and stomata for absorbing gases, but having no digestive organs. The foods absorbed are either liquids or gases, but never solids.

2. *Circulation.*— In *animals* circulation is brought about by a heart and blood vessels, or something corresponding to them. In *plants* the water absorbed from the roots ascends the stem, and passes out into the leaves by a process known as the *ascent of sap*, and the materials formed in the leaves are dissolved and eventually diffused throughout the plant, passing downward in certain of the cells of the stem. There are no real blood vessels, no heart, no blood, and no definite circulation.

3. *Metabolism.*—In *animals* metabolism is essentially destructive. The animal uses as food organic compounds like carbo-

hydrates, fats, and proteids; combines them with oxygen, and, as a result, produces as waste products carbon dioxid, water, and urea. The foods are broken to pieces, and the energy thus liberated is utilized; see Chapter XV. In *plants* the process is primarily constructive, but there is in plant life both a constructive and a destructive metabolism. By the former the plant uses carbon dioxid, water, and nitrates, which are combined in the plant to form organic substances, like starches, proteids, etc., and in the combination solar energy is stored away. As an excretion, there are produced oxygen and water. The destructive process of plants is essentially like that of animals: the compounds built up by the first process are destroyed by the second. The total amount of construction in green plants is greater than the amount of destruction, and therefore the green plants store away organic products which may subsequently be utilized by plant life.

4. *Respiration.*— *Animals* usually have lungs or gills filled with blood; they always absorb oxygen, and eliminate the carbon dioxid. In *plants* the respiration is carried on through the stomata of the leaves; when carrying on photosynthesis, plants absorb carbon dioxid and eliminate oxygen; when not carrying on photosynthesis, the gas absorbed is oxygen and the gas liberated is carbon dioxid.

5. *Excretion.*— In *animals* carbon dioxid is excreted from the lungs, water from the skin and kidneys, and urea from the kidneys. In *plants* there is no well-developed excretory system, although gases are excreted through the stomata, and certain other substances may pass out through the bark or through the roots into the soil.

6. *Motion.*— The muscles of *animals* develop a high degree of motion. In *plants* motion is very rarely developed, although it is not wholly lacking, some plants being well supplied with motile power. They do not, however, have muscles; and when they have motion, they use other forms of mechanism.

7. *Support.*— *Animals* usually have a skeleton of shell or

bone, either internal or external. In *plants* the supporting structure is, as a rule, developed better than in animals, and consists of the great mass of wood or other resisting material found throughout the plant.

8. *Coördination.*— All *animals,* except the unicellular forms, have a nervous system, usually centering in the brain, which brings into coördination the various functions of life. In *plants* there is no coördinating system and practically no coördination of the different parts. Each part of the plant may live its life to a considerable degree independently of the others.

9. *Reproduction.*— The reproductive processes of *animals* and *plants* are very similar. Both produce eggs and sperms, and have a sexual reproduction; and in both there may be reproduction by an asexual method, although in animals the asexual reproduction is less common than in plants. In the higher animals the power of asexual reproduction is lost, while in even the highest plants the process of asexual reproduction has commonly been retained. In the higher members of both groups, sexual reproduction by eggs and sperms is universal.

THE MUTUAL RELATIONS OF ORGANISMS

The close relation of organisms to each other is evident, since all animals, as well as all colorless plants, are dependent upon green plants for their food. They vary greatly, however, in their methods of obtaining their food.

Food Habits

Plants may be divided into three groups, according to their methods of obtaining their food: —

1. **Autophytes** (Gr. *autos* = self + *phyton* = plant).— Plants which are not dependent upon organic foods, but are able to take care of themselves by subsisting upon the minerals from the soil, together with the gases from the air, are called **autophytes.** These include the green plants (*holophytic*) only; and strictly speaking, even these plants are in a measure dependent

upon others. The minerals that they absorb from the soil are available for plant life only after the bacteria and other soil organisms have acted upon them, the fertility of the soil depending upon its microscopic life. The autophytes, however, do not need organic food, and in this respect are much more independent than the other two groups.

2. **Saprophytes** (Gr. *sapros* = rotten + *phyton* = plant). — Plants which feed upon the dead bodies of other organisms are **saprophytes.** The plants usually included under this head are the *Fungi.** These constitute the scavengers of the world, and may be found everywhere in the soil or in bodies of water, where they consume whatever excretions of animals or plants there may be; or live upon dead roots, leaves, and branches; they live, indeed, upon various dead materials that have been derived either from animal or plant life. Such organisms are almost universally distributed over the earth, and they cause all decay and putrefaction, these two processes being the result of the destruction of organic material by *Fungi.* This class of organisms is ever at work around us, consuming the bodies of dead animals and plants.

3. **Parasites.**— Plants which live upon and feed upon other living organisms are **parasites.** In such cases we call the organism upon which they feed the **host.** Parasitism is very common among both plants and animals, nearly every species having special parasites feeding upon it. As a rule, the parasitic plants lack chlorophyll and belong to the group of *Fungi.* Both saprophytes and parasites are *holozoic.*

Animals have similar relations, although in some respects they are more complicated. No animals live a life quite independent of organic food, like the autophytes, since they lack chlorophyll. The great majority of animals are called **free-living,** but they feed upon dead organic material (vegetable or animal food), and in this respect resemble saprophytes. Quite a large number of animals also feed upon a living host, and are consequently **parasites.**

*Under *Fungi* are included bacteria.

Symbiosis

Among both animals and plants, however, we not infrequently find different individuals associated and living in mutual relations which may or may not be those of parasite and host. The term **symbiosis** (Gr. *sun* = with + *bios* = life), which may refer to either animals or plants (literally meaning living together), is applied to a variety of relations where two organisms live in close relation to each other, and is in contrast to free-living conditions where organisms live separately from others. The purpose of symbiosis is not always the same. Sometimes it is to the mutual advantage of both members; sometimes it is to the advantage of one and the detriment of the other, in which case it becomes parasitism. In accordance with the relation of the two members of the group, symbiosis may be divided into several types as follows: —

Helotism.— In **helotism** (Gr. *Helot* = a slave) one organism is enslaved by the other; neither is especially injured, but one does the work for the other. Among animals the best example of this is among the slave-making ants, where one species of ants makes a slave of another species, the slave doing all the work for the slave-maker. Both individuals carry on their life in satisfactory fashion, and neither is particularly injured by the relation.

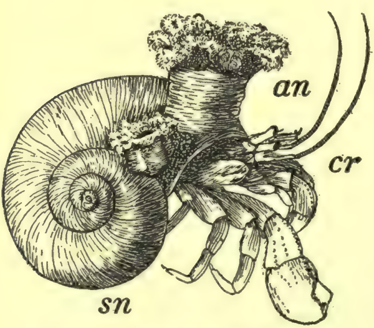

FIG. 105.—AN EXAMPLE OF MUTUALISM

A hermit crab *cr*, lives in the shell of the snail, *sn*, and an anemone, *an*, fastens itself to the outside of the shell. Both animals are benefited.

Mutualism.—When both members of a group obtain an advantage from association, it is called **mutualism.** As examples of this, may be mentioned the relation between domesticated animals, like

dogs, and the human race. Among lower animals the association of a hermit crab with a sea anemone is an illustration; Fig. 105. Here the anemone gains an advantage from being carried to and fro, while the hermit crab is protected by the nematocysts, which, as in *Hydra* (page 144), are abundant on the tentacles of the anemone, and which by their poison protect the crab from the attack of enemies.

FIG. 106.—*CLADONIA*; A COMMON LICHEN, GROWING ON ROCKS

At *B* is shown the young mycelium, beginning to grow around a single cell of the green alga.

Mutualism is rather more common among plants than animals. An example is the common gray mosses (*Lichens*) that grow on rocks or tree trunks; Fig. 106. The microscope shows that this plant is a combination of a fungus and a green plant; Fig. 107. In this association the green plant carries on photosynthesis, furnishing starch for both itself and the fungus; on the other hand, the fungus furnishes, for the benefit of the green plant, a lodging place and a considerable quantity of carbon dioxid and water, which it collects from the air. The association, therefore, seems to be one of mutual advantage. Another example is a group of bacteria which grows within

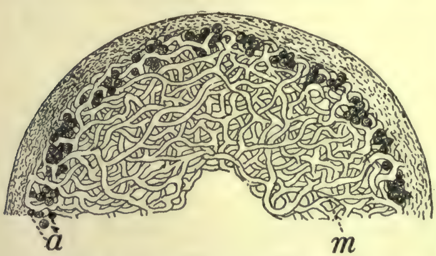

FIG. 107.—A MAGNIFIED SECTION OF A LICHEN

Showing that it is made up of a fungus, *m*, and cells of a spherical, green plant, *a*.

the little nodules on the roots of plants like peas and beans. If the roots of peas, beans, clover, or similar plants, be carefully removed from the soil, they will usually be found covered with little nodules ranging in size from the head of a pin to a large pea. These are found to be produced by bacteria which enter the roots and grow and multiply in their tissues. But the association is mutually advantageous. The bacteria are useful in collecting nitrogen from the air which the pea utilizes for its own benefit; and, on the other hand, the bacteria get the benefit of a lodging place and nourishment in the roots of the tubercle, and therefore are themselves benefited by the association.

Commensalism.— In **commensalism** (Lat. *cum* = with + *mensa* = table) the two organisms live together without noticeable advantage or disadvantage to either. As an example, may be mentioned the small crab that lives in the oyster shell, doing no injury to the oyster and gaining no special advantage. Various vines which cling to trees offer another example. Some of these vines force their rootlets into the tissues of the tree and do it injury; these are true parasites. But other vines simply use the tree for the support of their weak, climbing stem, and neither plant is particularly benefited or injured by the other, except that the vine is enabled by its climbing habit to send its leaves up into the sunlight.

Parasitism.— In **parasitism** the mutual relationship is such that one individual is benefited at the expense of the other. The host is always injured, while the parasite is benefited. Among parasites we recognize two types.

Ectoparasites.— Parasites that live upon the outside of their host are **ectoparasites.** As a rule, they are not very harmful, though they may be so. Among them are some in which a parasitic life is only a part of their existence. The mosquitoes live chiefly upon various juices, but occasionally suck the blood of human beings. In a second class, like the bedbug, the animals live wholly upon the nutrition from their host, but do not

attach themselves to the host permanently. A third type, like the lice, lives wholly upon its host and has no life apart from it. While these ectoparasites may be troublesome, they are not especially injurious, except when they transmit disease germs.

Endoparasites. — Parasites that live within the body of the host are **endoparasites.** They are numerous and produce far more mischief than ectoparasites. Among them are those that produce various deadly diseases like *trichinosis* (Fig. 108), *tuberculosis, diphtheria,* etc.

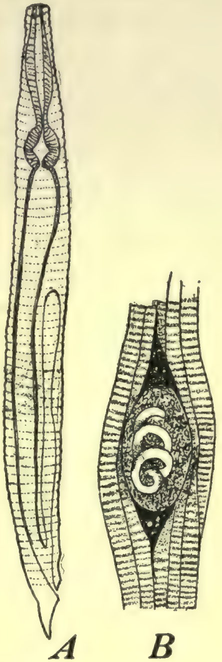

FIG. 108.—*TRICHINA*

A, a single worm showing its internal anatomy; *B*, worm coiled up in a bit of muscle of pork. If uncooked pork containing these worms is eaten they are set free in the intestines and a case of trichinosis results.

The Effect of Parasitism

Parasitism occurs among both animals and plants. The number of species of parasites is very great, but cannot be estimated. Nearly all species of animals and plants have their own parasites, and some have several species of parasites infesting them. For this reason it is sometimes stated that there are at least as many species of parasites as there are species of non-parasitic organisms. The effect of the parasitism upon both host and parasite is profound, but naturally quite different.

Upon the Host.—The parasite usually injures the host and is then spoken of as pathogenic (Gr. *pathos* = disease + *-geneia* = producing). The amount of injury varies widely. In some cases, the parasite produces disease and even the death of the host. *Trichina* is a parasitic worm (Fig. 108), which occasionally causes *trichinosis* in man, resulting sometimes in death. Certain flies occasionally make their way into the skull cavities

of cattle, producing serious and fatal brain disease. Malarial organisms (Fig. 25) live as parasites in human blood and produce *malaria.* Various parasitic bacteria produce serious diseases in man, as *typhoid fever*, *tuberculosis*, *diphtheria*, etc. The same is true of plants. The various *wilts*, *rusts*, and *blights* are serious plant diseases, frequently spreading from plant to plant, and producing death and destruction of the host. All are produced by parasites growing in the plant tissues. *Fungi* of various kinds are the cause of the greater number of plant

FIG. 109.—A WILLOW LEAF ATTACKED BY "MILDEW" CAUSED BY A PARASITIC FUNGUS

FIG. 110.—THE "BITTER ROT" OF CURRANTS

Produced by the parasitic fungus (*Gleosporium*). Most of the currants have dropped from the stem and the rest are rotted.

diseases; Figs. 109 and 110. In other cases, the effect upon the host is far less serious. Some parasites may live upon a host without seriously affecting it. For example, a number of bacteria live in our intestines; they may be called parasitic, since they dwell within a living host; but instead of being injurious,

some of them are beneficial to our life, and therefore are not true parasites, according to the definition given above. Between these two extremes are many intermediate grades. As a rule, parasitism injures the host, and indeed, strictly speaking, parasitism is a term that should only be used when one animal or plant feeds upon another, to the distinct detriment of the latter.

Upon the Parasite.— The effect of parasitism upon the parasite itself is no less profound than its effect upon the host, but it is of a totally different nature. The general effect of parasitism is to cause degradation of the parasite. It is a general law of living nature that *any organs which are not used, inevitably begin to degenerate.* If an animal becomes a parasite upon another, it shows a general tendency to lose many of its original characters. For example, the tapeworm has become parasitic in the intestines of animals. Here it finds its food already digested by the digestive juices of the host; it has thus no need of a mouth, of digestive organs, or of any power of motion; and, in conformity with the above law of nature, having no need of these functions, it has lost them. The tapeworm has thus become degraded to a very simple organism, without digestive organs and with all of its systems of organs reduced to the lowest possible condition. Thus, parasites, depending as they do upon their host for their nourishment, lose their power of independence and become degraded. This is a biological law of great significance,—the law that failure to use any function results in its loss,—running through the whole scale of nature. It is exemplified in the human race in numerous aspects of civilized life, where one class of people depends upon another. In our highly organized cities this principle of loss of power as a result of disuse is as well illustrated as it is among animals, since in the city individuals are so mutually dependent that each one has practically lost his ability to live by himself unaided by others. The principle of the loss of function by disuse is one of the most fundamental and significant of the laws of nature.

NATURE'S LIFE CYCLE

Construction and Destruction.— From a general survey of the facts which have thus been explained, it will be seen that there is a grand cycle in nature, in which the life of animals and plants is concerned. All organisms need food, and the only explanation of the fact that the food supply has not long since been exhausted is the fact that the same materials have been used over and over again, passing from plants to animals and from animals to plants. The chemical processes going on in the living world are of two types: those of construction (*synthetical*), by which complex substances are built out of simple ones; and those of destruction (*analytical*), by which the complex materials are reduced to simpler ones. Green plants growing in sunlight manufacture starch out of the simple ingredients which they extract from the soil and the air, utilizing sunlight as a source of energy for this purpose. Though they are building up these materials primarily for their own life, they build more than they need, so that there is a large surplus. This surplus is utilized by animals and by the colorless plants. It is taken into their bodies as food, and serves them as a source of energy, as well as material out of which they can manufacture new substances, and grow. Eventually the material is broken to pieces in the animal body and reduced once more to a simpler condition. In this way animals utilize as food a part of the surplus manufactured by green plants, consuming the surplus of proteids, starches, etc. But other materials made by the plants, like wood and leaves, do not so readily serve as food for animals. These materials must usually be broken down into simpler compounds, or the substance of which they are made would not get into a condition where it could again be utilized. This seems to be the special function of the *Fungi*.

The Significance of the Fungi in Nature.— Special emphasis must be given to the significance of the *Fungi* in these destructive processes. In order that nature's processes may

continue indefinitely, all kinds of material that have been built up into organic compounds by the green plant must be pulled to pieces again so as to be brought back into the simple condition in which the future generations of plants can utilize them. While animals use and break down much of the proteids, starches, and fats, there are some substances that animals cannot utilize, and the *Fungi* are necessary to reduce these substances to a simpler condition. *Bacteria* everywhere in nature are constantly feeding upon many kinds of organic substances, but primarily upon those that contain proteids or other nitrogenous compounds. The *yeasts* have a special relation to sugar; most of the sugars made by plants, and not otherwise used, are consumed by yeasts in fermentation and are thus brought back to the original condition of carbon dioxid and water. Bacteria and yeasts as well as animals thus feed upon the same substances. But there is other material of harder nature, like wood and leaves, which does not serve as food for animals nor to any great extent for bacteria or yeasts. The *molds*, *mushrooms*, and *tree fungi* seem to be especially designed by nature to attack these hard materials and reduce them to a condition in which they can be destroyed. These larger fungi consist of a mycelium of delicate, branching threads. If one of these plants starts to grow on the trunk of a tree, the mycelium pushes its way through the bark and in among the wood fibers, and eventually grows through the whole substance of the tree, the part visible on the outside of the trunk being only the spore-producing portion that has come to the surface to distribute the spores to other trees. The mycelium, while growing within the wood, produces certain substances which soften the wood and in time disintegrate it, *i. e.*, cause it to *rot*. A tree attacked by one of these *Fungi* in time becomes soft and so changed in its chemical nature that it can be utilized as the food of some insect. Eventually the trunk of the tree is converted largely into a soft, pulpy mass, until finally it is wholly decomposed. Its carbon and hydrogen unite with

oxygen, forming CO_2 and H_2O, which pass off into the air or sink into the soil, while the other ingredients are incorporated with the substances of the soil to form food for the next generation of plants.

The *Fungi* thus have the extremely important function of bringing back into a primitive condition much of the material manufactured by plants which otherwise could not readily be disposed of. When we consider that bacteria are nature's agents for decomposing proteids, that the yeasts act in a similar way upon carbohydrates, and that the larger *Fungi* attack the great mass of vegetable material which is otherwise beyond the reach of animal life, we can see that the group of *Fungi* is of immense significance in nature. They form a connecting link between the products of one generation of plants and the next. Without their agency, organic material — proteids, fats, starches, leaves, woods, etc. — would accumulate, and in time vegetation would cease, because the earth would be covered with the remains of past generations, which would crowd life out of existence. The *Fungi* thus act as scavengers, cleaning up the surface of the earth and rendering nature's processes continuous by ever returning to the soil the ingredients upon which subsequent generations can feed.

The Food Cycle Complete.— Thus, as the result of the action of the *Fungi* and of animals, all of the surplus starch and sugar, all the fat, proteids, wood, and cellulose, and indeed all other materials which have been built up by the constructive processes of plants, are eventually broken down, and in the end reach a condition like that from which they started. Carbon dioxid and water are produced, as well as nitrates and certain other mineral salts. The carbon dioxid, being a gas, flies off into the air to join the store of this gas in the atmosphere; the water evaporates or sinks into the soil; and the nitrates and other mineral ingredients also find their way into the soil. These ingredients, again within reach of plant life, are seized by the green plants and built up into a new generation of plants to

make new starch, sugar, proteids, etc. The ingredients which feed one generation of plants may, after combination in the plant body, nourish a generation of animals, eventually returning to the same conditions as those from which they started. The cycle is thus complete, and there need be no danger of exhaustion of the food supply as long as it is possible for the same materials to be used over and over again by green plants, animals, and fungi

CHAPTER XII

REPRODUCTION: SEXUAL AND ASEXUAL METHODS

GENERAL TYPES OF REPRODUCTION

The process by which reproduction is brought about is always fundamentally the same. In spite of all of the numerous modifications of the method in different animals and plants, they are all reducible to some form of **division**; the original animal or plant divides itself into parts, each of which is capable of growing into an individual like the one from which it came.

The numerous varieties of reproduction may be grouped together under two general types. In one of these the original organism divides itself directly into two or more parts by simple division. In the other the division is always complicated by the union of two parts with each other. In the latter case certain cells of the original organisms unite with each other, and the union is followed by a rapid division of the cells. The two types of reproduction are, therefore, (1) *Division unaccompanied by cell union* and (2) *Division accompanied by cell union.* The type of division in which cell union is found is often spoken of as *sexual reproduction*, and the uniting cells are the *sex cells;* the type in which the division is not accompanied by cell union is called *asexual reproduction.*

REPRODUCTION IN UNICELLULAR ORGANISMS

Simple Division.— All of the single-celled animals multiply by the process of simple division; Figs. 19, 23. A careful study of the internal changes that are going on in the cells during this reproduction shows that they are essentially identical with those described on pages 85–89. In other words, there is a division of the chromatin material in the nucleus, followed by the formation of two nuclei, which again is followed by the division of the cell into two parts. After having

thus divided and separated from each other, each of the individuals grows until it is ready to divide, and so the process goes on repeating itself. In most unicellular plants, the method of reproduction is essentially the same. Figure 30, for example, shows the reproduction in *Pleurococcus*, and Figure 33 in ordinary bacteria. These latter plants are so small that we cannot determine the internal changes that are going on, but can only see that the individuals elongate and then divide in the middle, into two parts. Recent study, however, seems to suggest that the changes are essentially like those occurring in the *Amœba*, and at all events the process of reproduction is nothing more than the process of division.

The reproduction of yeast by budding (*gemmation*) is only a modification of division; Fig. 32. The internal changes are essentially like those in the reproduction of the *Amœba* or *Paramecium;* the first step is the division of the nucleus into two, one of which passes out of the original cell into the bud, while the other remains in the original cell. Thus, when the two cells separate, each has a nucleus that has come from the original nucleus, and, while the details of the process are somewhat different, it is as truly a cell division as in the other examples. Nearly all of the unicellular animals and plants show one of these two methods of reproduction; see Fig. 111.

Reproduction by Spores.— When the organism breaks up into *many* parts, they are called **spores.** Examples of this we have already noticed among the unicellular organisms. In the yeast (Fig. 32 *s*), spores are formed within the yeast cells under some conditions; and Figure 25, which shows the life history of the malarial organism, indicates that one part of its history, namely, the cycle in the human blood, is an illustration of spore formation. In the malarial *Plasmodium* the spore formation which occurs in the human blood alternates with a second type of spore formation in the body of the mosquito. This last process is, however, associated with cell union, as shown in Figure 25 *j*. Among unicellular animals

spore formation is unusual, except in cases where it alternates with a cell union, as in *Plasmodium*. Among bacteria there is a spore formation of a peculiar kind. Here, as shown in Figure 33 *E*, each bacterium produces a single spore only, instead of several, and the spore formation is really not a form of multiplication. The cells formed are, however, called spores, although their function seems to be to resist adverse conditions rather than to reproduce the organism. They have resisting walls and are capable of developing into new individuals, thus agreeing with other spores except in the fact that one only is produced in a cell.

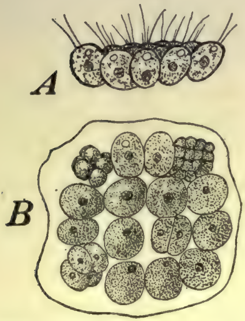

FIG. 111.—*GONIUM*. AN ORGANISM FORMED OF SIXTEEN CELLS UNITED BY JELLY

A, view from the side; *B*, view from above and showing the method of reproduction by division of each cell into sixteen parts, which separate to form new colonies.

Reproduction by Cell Union among Unicellular Organisms.— The process of cell division among single-celled organisms may continue for a long time, producing an indefinite series of offspring. Whether in any case this kind of division can really go on indefinitely we do not positively know. There are some organisms like yeast and bacteria, in which we have reason for suspecting that cell division may go on indefinitely if proper conditions can be maintained, and in which, up to the present, no trace of any other kind of reproduction has been found. It is believed by some that even animals like *Paramecium*, which conjugate occasionally, may, if proper conditions be maintained, go on dividing indefinitely. Whether this is true or not, it is certain that under ordinary conditions cell division in time becomes slower, and in *Paramecium* it has a tendency to come to an end, unless it is reinvigorated in some way. In nature such an invigoration is brought about by a fusion of cells with each other as already described; see Fig. 23, page 64.

It is probable that in most other unicellular organisms a similar cell union occurs under some conditions. As already described, it occurs in the malarial organism in the cycle that takes place in the mosquito; Fig. 25 *j*. The cell union that takes place is a true sex union, since there is a clear distinction of male and female cells. While such a union of cells has by no means been found in all unicellular organisms, it has been found in many, and we know that it is quite widely distributed. The studies of recent years particularly have shown one large group of unicellular organisms called the *Sporozoa*, which live as parasites on various hosts, and show a cell union resembling that of malaria. Another example of this will be given here in illustration of the phenomenon of cell union among single-celled animals.

Monocystis.— In the earthworm may be found living a unicellular parasite known as *Monocystis*. This animal (see Fig. 112 *A*) is a single elongated cell possessing a nucleus, but with no other visible organs. The animal has no locomotor organs, although it does have a slight power of motion. Its method of reproduction involves a cycle, in which a cell union alternates with a formation of spores without cell union, but in a complicated manner. When ready to multiply, two individuals fuse with each other and become surrounded by a covering or cyst; Fig. *B*. Inside of this cyst both of the individuals divide. First the nucleus divides into many parts (see Fig. *C*), and later the rest of the protoplasm divides and collects around the pieces of the divided nuclei, thus making many small cells. Now the new cells from one of these individuals unite in pairs with the cells from the other. This step occurs within the cyst, but is shown separated from it in Figure *D*, *a*, *b*, and *c*, and it constitutes the cell union proper. When the cells fuse together their nuclei unite, forming a single nucleus, *c*, called the **fusion nucleus**, which divides into eight parts, at *e*, after which the whole cell divides into eight elongated cells (see *f*) known as **sporozoites**. Meantime a hard

shell is produced around the eight sporozoites and the whole cluster of eight is called a **sporoblast.** All of this has occurred within the original cyst, which has by this time become filled with a large number of these sporoblasts, each with its eight

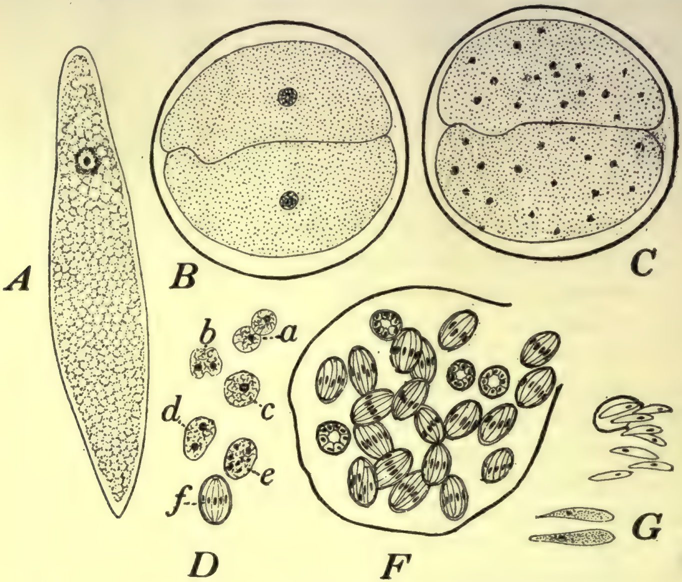

FIG. 112.—*MONOCYSTIS*, SHOWING METHOD OF REPRODUCTION

A, the full-grown animal; *B*, two individuals enclosed in a cyst; *C*, the division of the nucleus into a number of parts, the protoplasm not yet divided; *D*, successive stages of the fusion of the cells which result from division of the two animals in *C*; *F*, the cyst containing numerous sporoblasts; *G*, shows the sporoblast breaking open to allow the spores to emerge, which develop into adult animals. The stages represented in *G* occur only when the animal reaches another earthworm.

sporozoites within; see Fig. *F*. Eventually the cyst breaks open, allowing the contents to escape. Later these sporoblasts themselves break open and the individual sporozoites come out ready to grow into new animals like the original *Monocystis;* Fig. *G*. These latter stages do not occur unless the sporozoites find their way into another earthworm, where they live as parasites until ready to multiply again. The sporozoites are

evidently spores, but they arise from the division of a mass resulting from the fusion of two reproductive cells; and to distinguish them from other spores they are called sporozoites. By comparing this history with that of the malarian *Plasmodium*, it will be evident that the spores of the latter, which are formed in the body of the mosquito, must be sporozoites, since, like those just described, they arise from the breaking up of the mass of the two cells which have united by cell union. *Monocystis* as here described shows no spores which correspond to those that appear in the human blood; Fig. 25 *g* and *h*.

REPRODUCTION IN MULTICELLULAR ORGANISMS

Multicellular organisms have the same two general types of reproduction as found in the unicellular; namely, simple division, and division accompanied by cell union.

DIVISION WITHOUT CELL UNION

Multiplication by Simple Division.— Simple division among multicellular organisms is more common among plants than among animals; and excellent examples of it are familiar to all. Many of the lower plants, like *liverworts*, multiply by the formation of buds called **gemmæ,** which break away from the original, and form new plants. Even among the higher plants the same general method is found. If one of the branches of a weeping-willow tree is broken off and stuck into moist ground, it will take root and grow into a new tree. Indeed, we can cut the branches of a willow into practically as many pieces as we wish, and find each one is capable of taking root and growing into a new tree. The same thing is true of most ordinary plants, for, with a few exceptions, trees and smaller plants may be reproduced indefinitely by breaking off their branches and putting them into the proper conditions for taking root. While a few plants fail to show this power, it is a character found very commonly in the vegetable kingdom. Many plants normally multiply upon a similar principle. The strawberry

plant, for example, sends out branches which grow for some distance, and then their tips strike root into the ground and a new plant springs up, united with the old one at first by a connecting branch; Fig. 113.

Among animals this method of reproduction is not so common as in plants and is confined to the lower species. One example has been already described in *Hydra;* see page 146.

Reproduction by division is evidently closely related to the power of replacing lost parts. *Hydra* may be divided into many

FIG. 113.—REPRODUCTION IN A STRAWBERRY PLANT BY DIVISION

pieces, each capable of producing *all* of its lacking parts; but this power is retained in diminishing degree as we go from lower to higher animals. The earthworm does not ordinarily multiply by simple division, but if it is cut into two pieces by accident, each will develop the lost parts and two animals will result. In some worms, related to the earthworm, this method of multiplication by division, each piece developing all of the lost parts, is a normal method of reproduction; Fig. 114.

Reproduction by Spores.— Reproduction by means of spores is also found among the multicellular organisms, especially among the multicellular plants. A few illustrations of it are the following:—

Examples of spore formation in molds have already been described (page 97), two methods having been mentioned. In *Mucor* (Fig. 42 *E*) the spores are produced within a sac called a **sporangium,** while in *Penicillium* (Fig. 42 *A*) they are only the ends of branches, growing in the air. The latter are called **conidia** to distinguish them from spores formed in sporangia. The nature and function of spores and conidia are the same.

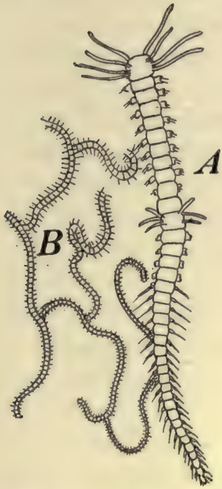

FIG. 114.—TWO SEGMENTED WORMS, WHICH MULTIPLY BY ASEXUAL METHODS

A, *Autolytus*, multiplying by division; *B*, *Syllis*, multiplying by budding, the buds growing from the side and breaking away to form new individuals.

Another well-known illustration of the same is the common *puffball.* This is a colorless plant, growing from a mycelium which lies chiefly below the surface of the ground. At certain seasons of the year there arise from the mycelium, rounded knobs which rapidly increase in size. They may grow as large as a walnut or an orange, and in some species they reach a diameter of a foot, or even two feet; see Fig. 115. Within this great mass the contents divide into millions of spores, and after they have been properly matured an opening appears at the top and the spores emerge in the form of a fine dust. The slightest touch upon the puffball will throw masses of dust into the air, from which arises the name puffball. This dust consists of millions of minute spores, each of which can become a new plant.

FIG. 115.—A PUFFBALL SHOWING THE SPORES PROTRUDING FROM THE OPENING

This power of producing spores is widely distributed among

plants, occurring in the lower as well as in the higher. Even in the flowering plants the pollen of a flower is really a mass of spores, although their relation to the growth of the plant is different from that of the spores to the puffball, since they do not grow immediately into a plant like the one that produces them.

Among the multicellular animals, the production of spores is not found. There is, however, in a few animals a method of reproduction, called **parthenogenesis,** which in some respects resembles spore formation. The essential differences between reproduction by spores and that by eggs is that a spore grows into a new organism without being united with a sperm, *i. e.*, no fertilization is required (see page 267), while an egg must combine with a sperm in order to be capable of growing into a new organism. Some organisms, however, produce eggs that can grow without fertilization. Among the best-known examples of this is the honey bee. The female bee produces true eggs, some of which unite with sperms, while others develop without such union. The individuals produced from the unfertilized and from the fertilized egg are different, the fertilized eggs producing worker bees or females, and the unfertilized eggs producing males (drones). So far as can be seen the eggs are alike, the only difference between the eggs that produce workers and those that produce males being that one is fertilized and the other not. This phenomenon of the development of eggs without fertilization is called **parthenogenesis** (Gr. *parthenos* = virgin + *genesis* = creation). It resembles reproduction by spores only in the fact that it consists of a single cell developing into an adult without the necessity of union with a sperm; but the reproductive bodies are identical with eggs, and it is usually described as reproduction by eggs which do not require fertilization.

Parthenogenesis occurs in a variety of animals with various complications. Where it occurs it is most common to have such a parthenogenetic reproduction alternate, with more

or less frequency, with sexual reproduction. In the microscopic animal *Hydatina*, for example (Fig. 116), found in fresh water, the eggs commonly produced, called **summer eggs,** develop without fertilization into new females, which rapidly mature and produce more similar eggs that develop in the same way. This may go on for a long time, under proper conditions for hundreds of generations, without any males making their appearance. Eventually, however, under conditions not yet understood, males make their appearance and the females produce eggs of a different kind, called **winter eggs,** which are incapable of developing without being combined with sperms by the sexual process. Here, then, parthenogenesis seems to be the normal method of reproduction, sexual reproduction alternating with it at unknown and uncertain intervals. The reasons for this alternation, and the conditions that determine the one or the other method, are not yet understood.

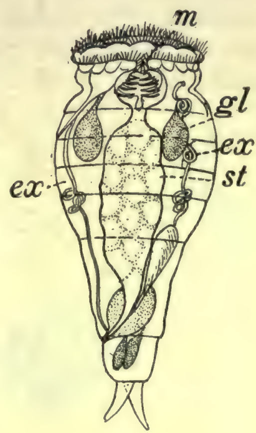

FIG. 116.—*HYDATINA*. A MICROSCOPIC ORGANISM THAT MULTIPLIES BY PARTHENOGENESIS

ex, excretory system;
gl, gland;
m, mouth;
st, stomach.

MULTIPLICATION BY CELL UNION

Conjugation.— In all animals above the unicellular forms, and in most plants, cell union is found as a factor in reproduction. Among a few plants of the lower orders the cells which unite are alike. In *Mucor*, for example, besides the spore formation mentioned on page 97, a union of cells sometimes takes place; Fig. 117. As shown in Figure *A*, special lateral threads grow out from the ordinary mycelium of the mold, and these come in contact with each other at their tips. After they touch each other single cells are divided off from each, *B*, which fuse with

each other, as shown at *C*. This fused mass is called a **zygospore** (Gr. *zygon* = yoke + *spora*), *z*. It enlarges, becomes covered with a hard case, *D*, and breaks away from the plant that produced it. It may then remain dormant for a long time, but eventually it sprouts, *E*, and grows into a new plant. In this case the two cells that unite are, so far as the microscope discloses, alike, and the plants that produce them appear identical. But careful study has proved that there is a difference in the uniting plants, shown not in their shape, but in their uniting powers. It has been found that there are two

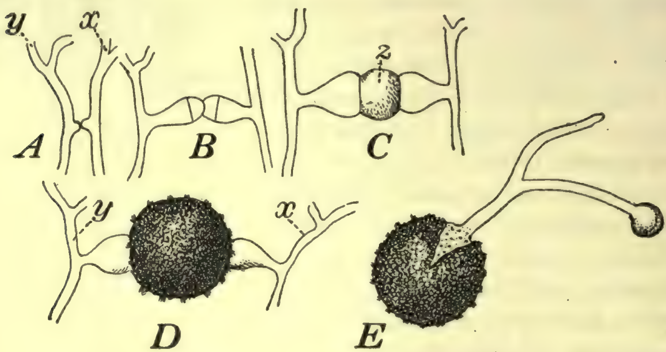

FIG. 117.—CONJUGATION OF *MUCOR*

Successive stages being shown in *A* to *E*; *x* and *y* are threads from different plants, which unite by conjugation; *z*, the zygospore; at *E* the zygospore has sprouted to form a new plant.

types of *Mucor*, differing only in their power of uniting with each other. For example, in Figure *A*, the two different mycelium threads are marked *x* and *y*. It is found that while outgrowths of *x* can unite with outgrowths of *y*, they can never unite with other outgrowths of the mycelium *x*. There are thus two different types of plants, each capable of uniting with the other, but not capable of uniting with outgrowths from itself. This reminds us of sex union, where an egg will unite with a sperm but not with another egg. It cannot be called true sex, however, since there are no distinguishable differences

between the uniting bodies. It is thought to be a first step toward the true sex which is developed in higher plants. Since the uniting bodies in *Mucor* are, so far as can be seen, alike, the union is called **conjugation.**

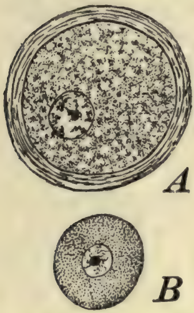

FIG. 118.—EGGS. *A*, OF AN ANIMAL; *B*, OF A PLANT

Among multicellular animals conjugation is unknown, true sex union being always found instead.

Fertilization or Sex Union.— The *eggs* of all organisms consist of single cells which have prominent nuclei; Fig. 118. Eggs are usually rounded in shape, although they may vary. In size they range all the way from eggs that are too small to be seen without the microscope, up to the size of the ostrich egg. The size of the egg is by no means proportional to the size of the animal that produces it. The human egg, for example, is microscopic, and the egg of the hen is gigantic in comparison. In large eggs, like those of the hen or the ostrich, the bulk of the egg is made of food material, sometimes called *yolk*, or *deutoplasm* (Gr. *deuteros* = second + *plasma* = substance), deposited within the eggshell for the nourishment of the young which is to be developed. The egg has a thin cell wall which is known as the *vitelline membrane.*

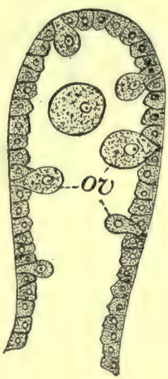

FIG. 119. — DIAGRAMMATIC SECTION OF THE OVARY OF AN ANIMAL

Showing the origin of eggs from the ordinary cells. *ov* ova.

The eggs of animals are produced in organs called the **ovaries**; Fig. 119. They are situated in different parts of the body in different animals, and their sole function is to produce eggs, which are then carried to the exterior through ducts called the **oviducts.** As can

be seen from Figure 119, the egg is really a single cell, like the other cells of the body in structure, though larger in size. As the egg passes along the oviduct it is not infrequently surrounded with a mass of **yolk** and a **shell**; neither the yolk nor the shell is an essential part of the egg, the yolk being a food material for the nourishment of the embryo, and the shell being a covering to protect the egg after it has left the body.

Plants also produce eggs similar in structure to those of animals (Fig. 118 *B*), though the organs that produce them are not called ovaries.*

Sperms.— Sperms are extremely minute cells which must unite with the eggs in order that the latter may be capable of further development. Sperms are by no means uniform in shape. As a rule, each consists of a minute head and a motile tail, whose lashing movements propel the sperm through liquids until the sperm is brought in contact with the egg. Figure 120 shows the sperms of a number of animals and plants. There is great variety among them, and, while some of them are provided with tails, others are not, and, although usually motile, the sperms of some animals are stationary. The sperms of animals are produced in special glands called **spermaries** or **testes.** In the frog and earthworm the position of these sperm glands is shown in Figure 80. The sperms are passed from the spermary into ducts, commonly known as the **vasa deferentia,** which carry them to the exterior. These ducts may be

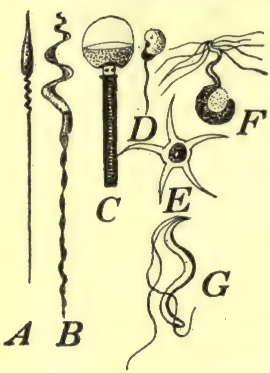

FIG. 120.— VARIOUS FORMS OF SPERMS

A, B, C, D, and *E*, sperms of animals; *F*, of a fern; *G*, of a liverwort.

(Various authors.)

* It will be noticed that the ovary of an animal is quite different from the ovary of a flower, since the latter does not produce eggs nor have oviducts; see page 273.

very short or they may be long and coiled. Sperms are much smaller than eggs, the sperm being always microscopic. Plants also produce sperms (Fig. 120 *G*), though they do not come from spermaries or special sperm ducts; see page 271.

Males, Females, and Hermaphrodites.— When reproduction in animals or plants is brought about by eggs and sperms, the process is spoken of as **sexual reproduction** and the uniting bodies, the eggs and sperms, are **sex bodies.** The glands that produce them are the sexual glands, or **gonads,** and the ducts that conduct the bodies to the exterior are the **sexual ducts.** Among animals, it is most common to have one individual produce either spermaries or ovaries, but not both, and the individuals are then spoken of as males and females.*

In some animals, however, as already seen in the earthworm, the same individuals may produce both spermaries and ovaries. Such individuals are spoken of as **hermaphrodites.** Among animals hermaphrodites are found chiefly among the lower orders, very few being found among the higher. Among plants, however, both hermaphroditic and separate sexed conditions are common; hermaphroditic plants are called **monœcious** (Gr. *monos* = one + *oikos* = house), and the separate sexed plants **diœcious** (Gr. *di-* = twice + *oikos*). In the higher flowering plants the relation of the sexes is peculiar, and complicated by what is called alternation of generations, to be described later.

THE UNION OF THE SEX BODIES OR FERTILIZATION

The union of the egg and the sperm is called **fertilization,** and the moment when the egg and the sperm unite is the beginning of the life of the new individual. This process of union of the sex bodies is peculiar and of extreme significance. In the description which follows, the successive changes which occur are described without reference to any particular spe-

*The sign ♂ is used to denote the male sex, ♀ to denote the female sex, and ☿ to denote hermaphrodites.

cies. Essentially the same series of events occurs in all animals where a fertilization takes place, although the order of events is not always the same. In a previous chapter we have seen that in all animals, when the chromatin of the nucleus breaks into chromosomes before division, the number of chromosomes is always the same in all cells of the species. In order to illustrate the process of the origin and union of the sex cells, we will describe the process in an animal that has four chromosomes, meaning by this that all of the cells of the animal (except the germinal cells to be described) contain four chromosomes at the time when cell division takes place.

Origin of the Egg (*Oögenesis*).— The egg is simply one of the ordinary cells of the ovary. During the early life of the animal, the cells in the ovary increase by the ordinary process of cell division, with nothing especial to distinguish it from the cell division of the other cells. In all cases, the cells are about the ordinary size and all contain the normal number of four chromosomes. This process continues indefinitely during the early life of the animal, until it is ready to produce eggs. When this time comes, some of the cells of the ovary begin to increase greatly in size, and become in a short time very much larger than the ordinary cells, not only than the cells of the body generally, but much larger than all of the other cells in the ovary. This increase in size is due largely to deposition in the egg of food material which is to serve as nourishment for the young that is subsequently to develop from the egg. At the time the egg increases in size, a peculiar change takes place in the chromosomes within the nucleus. By a series of divisions, this chromatin divides into a number of chromosomes which is always *double* that found in the ordinary cells of the animal. In our illustration, instead of four of these chromosomes, there are eight. These chromosomes always assume at this stage the arrangement in groups of fours, such as is shown in Figure 121 *A*. There is thus produced a large primary egg (Gr. *oön* = egg + *cytos*), called an **oöcyte,** containing

an immense amount of food yolk in it, and with double the number of chromosomes that are found in the ordinary cells of the animal. This doubling of the chromosomes is the last step in the formation of the oöcyte.

Maturation of the Egg.— At the stage shown in Figure 121 *A*, the egg is not yet mature, *i.e.*, is not yet ready to unite with the sperm; it must first pass through a further series of changes spoken of as the **maturation** of the egg. The nucleus approaches the edge of the egg and divides into two parts, one very large and one very small, each retaining four of the chromosomes present in the original nucleus; Fig. 121 *B-D*. It will be noticed that in this division the chromosomes do not split as they do in ordinary cell division (see page 87), but that each of the two nuclei formed contains half of the original eight. One of these nuclei is pushed out of the egg as a small protrusion shown at *D;* the other one remains within the egg. After a short period of rest the process of division is repeated,

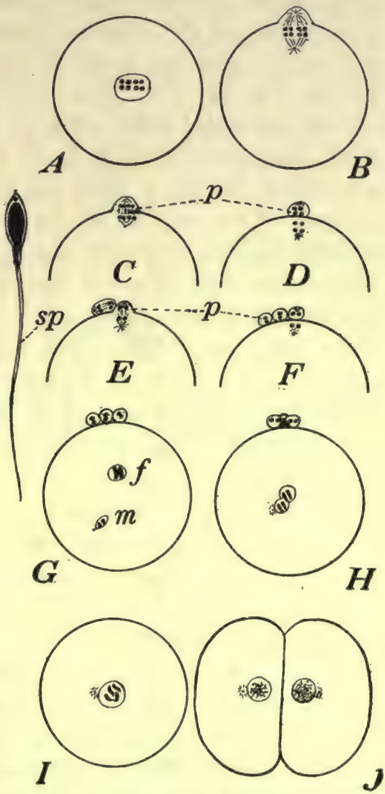

FIG. 121.— DIAGRAM SHOWING THE MATURATION AND FERTILIZATION OF AN EGG

Stages *A* to *G* represent maturation; *H* and *I* the fertilization; *J*, the egg after it has divided; *f*, female pronucleus; *m*, male pronucleus; *p*, polar bodies; *sp*, a typical flagellate sperm more highly magnified.

the two nuclei once more dividing into two parts without any splitting of the chromosomes, each of the four nuclei thus containing two of the original chromosomes. Half of the nucleus still within the egg is extruded, while the other half remains within; Fig. 121 *E*, *F*. The nuclei which are thus extruded from the egg are called **polar cells,** *p*, and have no further function, since they have nothing to do with the individual which is to arise from the egg. They are rejected products and soon disappear. After the nuclei have divided the second time, the nucleus remaining within the egg, with its two chromosomes, once more passes toward the center of the egg and is called the **female pronucleus;** Fig. *G*, *f*. The egg is now ready to unite with the sperm. The egg, in other words, has become mature, this process of the extrusion of the three small nuclei being the essential feature of the process of maturation.

The Origin of the Sperm (*Spermatogenesis*).— The origin of the sperm is essentially similar to that of an egg, differing, however, in one rather important point. As in the ovary, the ordinary cells in the sperm glands, during the early life of the animal, continue their growth and division by the process of simple cell division, with the normal method of the division of the chromosomes. When, however, the sperms are about to be formed, the cells of the spermary undergo a change similar to that described in the formation of the egg, except that they do not materially increase in size. In each of these cells, called a **spermocyte** (Gr. *sperma* = germ + *cytos*), the number of chromosomes doubles itself, producing a number identical with that found in the oöcyte; Fig. 122 *I*. The chief difference between this spermocyte and the oöcyte at the corresponding stage is that, whereas the egg has greatly increased in size by the deposition of the food, the cell which is to form the sperm does not increase in size.

The next step in the development of the sperm is the division of this cell into four parts. This step corresponds clearly with the division of the egg cell into four parts, as shown in

Figure 122 *II* to *III*. In this case, however, the division does not produce one large and three small cells, but four cells of equal size, each one of which receives two of the chromosomes. It is evident, therefore, that one of these cells is equivalent to

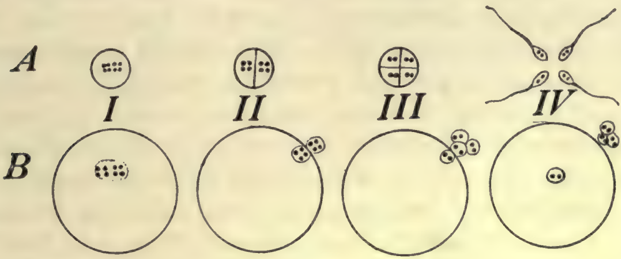

FIG. 122.— DIAGRAM SHOWING A COMPARISON BETWEEN THE MATURATION OF AN EGG, *B*, AND THE FORMATION OF THE SPERMS, *A*
Stages *I* to *IV* in series *A* and *B* correspond with each other.

one of the cells developing in the maturation of the egg, at least so far as concerns its nuclear matter and its chromosomes, differing, however, in the amount of cell substance that may be present. In the further development we find another point of difference in the fact that each one of these four cells develops into a perfect, functional sperm. In the maturation of the egg, three out of the four cells are thrown away and take no further part in the functions of the animal; in the development of the sperm, however, each one of the four cells arising from the divided *spermatocyte* cell becomes a typical sperm; Fig. *IV*. It is evident from this that a sperm must be regarded, so far as concerns its nuclear matter, as equivalent to a matured egg, and equivalent also to each of the three discarded cells which have been thrown away in the maturation of the egg. Both the sperm and the egg contain half the normal number of chromosomes.

An examination of a matured sperm shows the structure indicated in Figure 121 *sp*. It consists of a **head**, which is

sometimes rounded, but more commonly elongated. A careful examination of this head shows that it contains an equivalent of the two chromosomes originally present in the matured egg. The spermatozoan head is therefore really a nucleus. Just back of the head is a short piece known as the **middle piece,** which contains a centrosome. This is the smallest part of the sperm. The third part of the sperm is the **tail,** which is usually rather long and motile, and whose only function is to produce motion of the sperm and thus bring it in contact with the egg. The sperms of some animals, however, have no motile tail and are brought into contact with the egg by other means.

The important conclusion to be drawn from this description of the origin and structure of eggs and sperms is, that they are essentially equivalent to each other. Even though the egg is very large and the sperm is very small, and though the egg is motionless and the sperm is commonly endowed with motion, so far as concerns their most essential parts they are identical. Each contains one nucleus, with chromosomes equivalent to half the amount present in the ordinary cells of the organisms from which these cells were derived; each may contain a centrosome, though this is not always found. The eggs contain food upon which the young embryo feeds, and the sperm possesses a tail by which it can swim; but these are secondary features, and in essential characters the egg and sperm are identical.

Entrance of the Sperm into the Egg.— When the sperms are mature they are excreted through the ducts of the spermaries to the exterior. If not excreted into the water, as is frequently the case with water animals, a quantity of liquid is sometimes excreted with them, in which the cells can swim by their motile tail. All organisms have some method by which the sperms and eggs are brought together. Sometimes both of them are thrown in large numbers into the water and depend upon chance currents to bring them together. Among many of the higher animals there are developed special **copulatory organs,** whose function is to bring the eggs and sperms together. Among

the endless series of animals and plants may be found great variety in the manner by which this is accomplished; but in all cases some efficient device is found for bringing the egg and sperm into contact.

The egg and the sperm have a strong attraction for each other, so great that when brought into each other's proximity the sperm will be attracted to the egg and attach itself. The head of the sperm then buries itself in the egg, as shown in Figure 121 *G*, *m*, the tail being left on the outside, but the centrosome being carried in with the head. The tail has no further function. This entrance of the sperm into the egg may occur either before or after the changes in the egg that have been described as maturation. If the sperm enters before the egg is fully matured it remains in the egg in a dormant condition, and is now known as the **male pronucleus,** until after the egg has been brought into the condition above described as mature, with its chromosomes reduced to half their normal number. If the sperm does not enter the egg until after the egg is mature, the further changes which bring about fertilization occur at once.

Fertilization.— After the sperm has entered the egg and the egg has become matured, the nucleus of the egg and the sperm head (the two pronuclei) approach each other; Fig. 121 *H*. What brings them together is not exactly known; apparently, in some cases, the centrosome seems to have something to do in bringing the two nuclei in contact, and without much doubt they have an attraction for each other. At all events the egg and the sperm are soon brought together and finally fused with each other, forming a single **fusion nucleus.** This fusion is the **fertilization** proper (sometimes called *impregnation*). Since the egg nucleus contains two chromosomes and the sperm head, or male nucleus, also contains two, when these two unite the fusion nucleus evidently contains four of them, and thus the number of chromosomes is restored to the same number as that possessed by the ordinary cells of the body

of the animal. Whether the centrosome that is brought in by the sperm and that which comes from the egg have anything to do with the subsequent history of the fertilized egg, is uncertain. In some cases it is certain that the centrosome of the original egg disappears, and the only one that remains is the one brought in by the sperm. In plants, as we have already learned, there are no centrosomes at all, and from these facts it would seem to follow that the centrosome can not have very much to do with the process of fertilization.

From the facts given it is evident that the fertilized egg contains material from both parents. The female parent furnishes the bulk of the food in the egg upon which the young is to be nourished; and it also furnishes two chromosomes. The male parent has also furnished two chromosomes, and in some cases a centrosome, but none of the food material. The only thing which the two sexes have furnished in common is chromatin material, and it is especially interesting to note that both the male and the female parent furnish chromosomes in *equivalent amounts.*

Unless an egg is fertilized by a sperm it has no power of subsequent growth. Most of the ordinary cells of the animal body are capable of a certain amount of development, but the egg cell if unfertilized soon dies, undergoes decomposition and disappears. The sperm cell also is unable to undergo any development by itself. Therefore, the fusion of an egg and a sperm is necessary, in this type of reproduction, for the development of a new individual.

It may sometimes happen that more than one sperm is brought into the vicinity of an egg. When this occurs, in most cases there is some device by which the entrance of more than a single sperm into the egg is prevented. In some kinds of eggs, it is, however, not unusual for more than one sperm to enter the egg, but when this occurs only one of them unites with the egg nucleus, the others having no further function in the process. If in any case more than one sperm

does unite with the egg nucleus, abnormal results arise and no proper embryo develops. In the vast majority of cases, however, the single sperm unites with the single egg nucleus, and all other sperms that chance to be present have nothing to do with the development, but soon disappear.

THE RELATION OF THE CHROMATIN TO HEREDITY

The facts just mentioned show us that the chromatin must play a very important part in the transmission of characters from parent to offspring. It is a demonstrated fact that both the male and the female parents can transmit their characters equally to their offspring. It follows that both parents would probably transmit an equal amount of hereditary substance to the next generation. The process of fertilization just described shows that the only parts contributed by the male parent to the fertilized egg are the centrosome and the chromosomes. Hence whatever the male parent transmits to its offspring must be contained either in the centrosome or the chromosomes. But the female parent does not contribute any centrosome to the combined egg, and it should be remembered that in plants there is no centrosome. The female does contribute an amount of chromatin equal to that which the male contributes, namely, in the case described, two chromosomes. This fact proves that the chromosomes must certainly contain hereditary material. These chromosomes are extremely minute, far below the reach of the human vision and only seen with a high-power microscope and by special microscopic methods. It seems almost incredible that there can be in such a small compass the traits of characters which an individual transmits to its offspring and which the offspring inherits from its parents. But the facts described seem to be capable of no other interpretation, and we are therefore justified in saying that the chromatin material is the bearer of heredity. This does not necessarily mean that other parts of the egg and sperm may not have some share in heredity.

The methods of maturation and fertilization differ somewhat in different animals and plants, but in all cases where there is the union of the egg with the sperm it is essentially as above described. The normal number of chromosomes is first doubled and then reduced to one-half that which the ordinary cells of the organism originally contained. The mature sperm also contains half of the normal number of chromosomes; and thus, when the egg and the sperm finally fuse, the nucleus of the fertilized egg is always brought back into the original condition with the normal number of chromosomes, which is evidently always an even number; see page 85.

It may seem a little strange that the egg should exclude and throw away as useless such a considerable part of this chromatin material, which must be of such great value. The reason is not difficult to see. If the egg did not throw away some of its chromatin material, it could not combine with the sperm without the chromatin material in the combined egg being doubled in quantity. If, for instance, in the case described, the egg and sperm should retain their normal number of chromosomes, then, after the egg and sperm united, the nucleus of the fertilized egg would contain eight instead of four, and all of the subsequent cells would necessarily contain eight. If the process were repeated at the next reproduction the number would again double and thus the amount of the chromatin material in each cell would become greater, generation after generation. To keep the number of chromosomes the same in successive generations, both the sperm and the egg throw away some of their chromatin to make room for an equal amount brought in by the other cell at fertilization. Why the number is first doubled before being reduced is not clear.

THE PURPOSE OF THE UNION OF THE SEXES

Since sex union is almost if not quite universal among animals and plants, it is evident that the process must be one of very great significance. One of its purposes is very

evident. Inasmuch as the chromosomes contain the substance which transfers the hereditary traits, it follows as a result of this cell union that the individual that is to arise from the fertilized egg will inherit traits of character, not from one but from two parents. This will naturally produce a greater variety in the offspring. If an individual arose simply as a result of the division of a single parent, it would be expected that it would have a tendency to show a much greater likeness to its parent than if it arose from the fusion of cells from two parents, each of which possessed its own individual characteristics. Thus, as a result of this sexual union, there will be introduced into the offspring a tendency toward variety, which would hardly be expected if they were produced always by the non-sexual methods of simple division. It is believed by biologists that one purpose of sex union is to produce variety among organisms, *i. e.*, to introduce what is technically called **variation.** The importance of variation will be discussed later; here it will be sufficient to say that upon the phenomena of variation is based the whole problem of the evolution of animals and plants, and therefore, without this phenomenon of sex union, the evolution of animals and plants could hardly have taken place, at least not in the form in which it has occurred in the actual history of living things.

The process thus becomes intelligible. Sex union brings about the combination in the offspring, of the qualities of two parents, and thus produces a succession of generations which, though much alike, still show a certain amount of variation among themselves and hence a variation from the ancestral type.

CHAPTER XIII

DISTRIBUTION OF SEXUAL AND ASEXUAL METHODS. ALTERNATION OF GENERATIONS

SUMMARY OF THE METHODS OF REPRODUCTION

REPRODUCTION in all animals and plants is the result of division, but according to whether the division takes place with or without cell union, we have the two following types:—

1. *Asexual reproduction.*— Asexual reproduction is division without cell union. Under this head there are at least four different methods.

A. Division by *fission.*

B. Division by *budding.*

C. Division by *spore formation.*

Each of these three types of reproduction is found among unicellular as well as multicellular organisms.

D. *Parthenogenesis*, or reproduction by eggs without fertilization.

2. *Sexual reproduction.*— Sexual reproduction is division preceded or accompanied by a union of cells, the uniting cells being called **gametes.** According to whether the uniting cells are alike or unlike, we find two types.

A. *Conjugation.*— When the uniting cells are microscopically identical with each other, the process is conjugation. In these cases there are neither eggs nor sperms, and the cell resulting from their union is a **zygospore.**

Conjugation has apparently for its purpose the reinvigoration of the process of cell division, since, after two individuals have united, cell division begins to take place more rapidly. After many generations of simple cell division the process tends to become slower, and conjugation then may occur to

reinvigorate the process. Conjugation occurs chiefly among the unicellular organisms. It is found also among some multicellular plants, but in no multicellular animals.

B. *Fertilization, or sex union proper.*— When the uniting cells are unlike, one being much larger than the other, their union constitutes fertilization, or true sex union. The larger of the two uniting bodies is the egg and the smaller the sperm.

ORIGIN OF SEX UNION

Conjugation and sex union are evidently closely allied. Indeed, some organisms show a type of reproduction that is halfway between conjugation and true sex union, and give us an idea as to what was probably the origin of sex. We have already studied *Pandorina* (Fig. 28), in which we found an animal multiplying by the union of two similar cells; but the two cells, although similar, are not exactly alike. Both are rounded cells, both provided with flagella which enable them to swim; but one is a little larger than the other, and when union occurs it is always that of a larger with a smaller cell. Whether this is a true sex union or a conjugation it is difficult to decide.

A step further in the line of sex differentiation is found in *Eudorina*. This organism is much like *Pandorina*, and is composed of a cluster of rounded flagellate cells, inclosed in jelly; Fig. 123 *A*. They multiply by a method of simple division as does *Pandorina* (shown at *A*), and in addition they multiply by cell union. In the latter case the cells break up into many small parts, after which there is a union of cells. But here the uniting cells are very unlike. Some of the cells, shown at *C*, *D*, *E*, break up into a large number of small flagellate cells, of an elongated shape. The other cells of the colony do not divide, but slightly enlarge and remain spherical. Eventually one of the small flagellate cells comes in contact with one of the rounded ones and the two unite. Here there is a plain suggestion of egg and sperm, and consequently of a true

sex union. Only one more step is needed to have a typical sexual reproduction. In *Eudorina* all of the cells of the colony share in the reproductive process. If only a few of the cells of the colony should thus develop into sex cells, leaving the colony to live an independent life, even after the sex cells have been extruded, there would be a typical sexual reproduction.

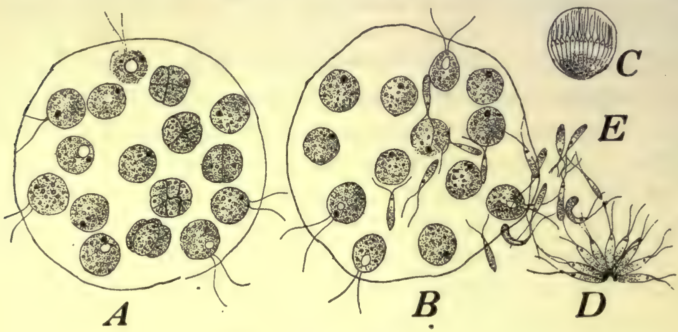

FIG. 123.—*EUDORINA*

A, showing the asexual reproduction by division. *C*, *D*, and *E* show some cells which are dividing into numerous flagellate gametes. These unite with the larger cells in *B*, which are thus also gametes.

Such a condition is found in the multicellular plants and animals generally.

From such data as these it is evident that the probable origin of sexual reproduction has been something as follows: The first method of reproduction was by simple division, but the independent individuals acquired the habit of fusing with each other, as we have seen in the case of the *Paramecium*, this fusion reinvigorating the life power of the fused individual. Next there was probably a tendency for the cells to break up into many parts which subsequently united with each other, the parts being at first all alike. The next step seemed to be for some of these cells to contain more food than the others and become larger; this led to the larger cells having less power of motion, while the smaller ones retained the power. Next

the larger cells lost their swimming flagella and were brought into contact with the smaller cells only by the motions of the latter, which still retained their flagella. Lastly, most of the cells of an organism ceased to have any share in reproduction, being simply concerned in the life of the colony. Some of the cells in such a colony, however, assumed as their part the process of uniting with others, and thus carried on the functions of reproduction. These cells still continued to differentiate into large and small cells, the large ones becoming eggs and the small ones remaining as sperms. From this time on the function of reproduction is independent of the functions of the life of the colony, and the individual exists apart from its offspring. From all of this it appears that conjugation is the first step in the direction of sex union, and that conjugation must therefore be regarded as a form of sex union, although the sexes have not been sharply differentiated in any true case of conjugation.

DISTRIBUTION OF ASEXUAL REPRODUCTION

Among plants asexual reproduction is nearly universal, all of the lower plants, and nearly all the higher ones, being able to multiply by some form of budding or division. *Parthenogenesis* is also fairly frequent. Among animals multiplication by budding or division is also widely distributed. It is universal among the unicellular animals, and is a common method of multiplication among such lower forms as *Hydra* and its allies. As we pass to higher animals this power disappears. It is found among some worms, and one group of animals related to the vertebrates (*Tunicata*) forms colonies by budding, which may break up and become several colonies, this constituting a modified kind of reproduction. In no other higher animals does asexual reproduction occur. The modified type of asexual reproduction which is called *parthenogenesis* is found among some of the higher animals, being fairly common even among insects.

DISTRIBUTION OF SEXUAL REPRODUCTION

Sexual reproduction, using this term to include conjugation, is very widely distributed among organisms and, indeed, is possibly coextensive with life. It is true that there are many forms of unicellular animals and plants in which it has never been shown to occur; but in many cases this is due to incomplete knowledge. With increasing knowledge, more and more of the unicellular organisms are known to go through the process of cell union under some conditions. Even some of the longest known and best studied organisms (*Amœba*) have been recently shown to undergo conjugation. Among some of the unicellular forms, too, there occurs a true sexual union. In the malarial organism, for example, there is at one stage in the life history a union of two unlike cells, which are regarded as male and female, and a similar differentiation of uniting bodies has been found in many other single-celled organisms. The continued discovery of new examples of sexual union or conjugation, among the lower organisms previously supposed not to have this power, has led to a belief that a union of cells in reproduction may be a universal characteristic of all life, even though there are still many of the lower animals and plants in which it has not been found. This conclusion is as yet by no means proved and may not turn out to be strictly true. In all groups of animals above the unicellular types, sexual reproduction, by the union of true male and female cells, is universal, and in the higher groups it is the only method of multiplication known to occur.

REPRODUCTIVE BODIES OR REPRODUCTIVE CELLS

This term refers to the parts which are separated from the bodies of animals or plants, and capable of growing into new individuals. Sometimes they are multicellular fragments, like the *buds* of *Hydra* or the *gemmœ* of a plant; but in such cases the term reproductive body is not usually applied to them. In the large majority of cases the bodies formed for reproductive

purposes are single cells which are capable of developing into new individuals, and hence the term **reproductive cells** better describes them. Of these reproductive cells we recognize the following kinds: —

Spores: single-celled reproductive bodies, capable of growing into new organisms without uniting with a sperm.

Eggs, or *ova:* large, stationary cells, which grow into new individuals only after uniting with a sperm.

Sperms: minute, usually motile cells, which must unite with an egg to enable it to develop.

Parthenogenetic eggs: large, stationary cells, resembling, or identical with, eggs, but able to develop without union with a sperm.

The name **gametes** (Gr. *gamete* = wife or husband) is frequently applied to the cells that unite with each other in cell union. This term, therefore, includes eggs and sperms, and also the uniting cells in conjugation where no distinction of sex is seen.

CROSS FERTILIZATION THE RULE

Cross Fertilization.— In ordinary sexual reproduction the rule is that a single sperm unites with a single egg. When the sexes are separate, as in the frog, this will always result in the fertilization of an egg from one individual with a sperm from another. As we have seen, some animals produce both eggs and sperms, and might fertilize their own eggs. But usually there is some device to prevent this. In the earthworm, although both eggs and sperms are produced by each individual, in copulation there is an interchange of sperm fluid, in such a way that the eggs of each individual are subsequently fertilized by the sperms from the other. This is called **cross fertilization.** In most cases where both male and female organs are produced in the same individual, there is some device by which cross fertilization is insured. In the

common flowers both male and female organs are developed in each flower, but there is almost always some means which prevents the flower from self-fertilization and insures cross fertilization. In a few animals and plants, it is true, self-fertilization appears to be the rule, but it is very unusual.

It appears that the reason why cross fertilization is so commonly found, is that it results in more or stronger offspring. Experiments carefully carried out in plants have shown that, in many cases at least, the offspring resulting from cross fertilization are more vigorous than those coming from close fertilization. In animals there is less evidence at hand on the subject, but here, too, it has been recently shown that, in some cases at all events, cross fertilization is more productive of a vigorous progeny. Apparently, then, cross fertilization is based upon a fundamental law.

Hybrids.— On the other hand, it is necessary that the sperm that unites with the egg shall come from another individual not too unlike the one that produces the egg. If the egg belongs to one species of animal or plant and the sperm to another species, they are not likely to unite at all. If two different species are crossed the rule is that there is no offspring, or that, if there is offspring, they will themselves be incapable of producing young. Such an individual is known as a **hybrid**, and frequently hybrids are *sterile*. It was at one time supposed that they were always sterile, a conclusion that was based largely upon the fact that the mule, which is a hybrid between a horse and an ass, is well known to be incapable of breeding. But most careful study of both animals and plants has shown many instances where hybrids are fertile, so that the sterility of hybrids is by no means a fixed rule. In general, however, in order to produce the most vigorous offspring it is necessary that the eggs of one individual should be fertilized by sperms from another individual of the same species, but not too closely related. Close *inbreeding* has a tendency to foster weakness.

ALTERNATION OF SEXUAL WITH ASEXUAL METHODS OF REPRODUCTION

In many plants, and in some animals, there is a regular alternation in the methods of reproduction, *i. e.*, that with sex union and that without sex union. This is commonly spoken of as the **alternation of generations.** One of the simplest and most easily understood examples is in that of the common fern.

Life History of the Fern. — At certain seasons of the year, usually in the fall, there appear upon the under surface of the fern leaves, or **fronds,** which grow everywhere by the roadside, little rounded disks known as **sori;** Fig. 124 *B*. They are sometimes covered by a little scale called an *indusium*. A study of these disks with a microscope shows that they are made up of a number of little sacs, containing minute reproductive bodies; Fig. *D*. When mature the sacs burst and the reproductive cells are thrown out into the air. If they fall upon some surface where they have the proper temperature and moisture, they begin to grow at once; and since

FIG. 124.— COMMON FERN

A, the fern attached to its root-stock; *B*, the back of two leaflets, showing the sori; *C*, a leaflet more highly magnified showing the sporangia within the sori; *D*, one of the sporangia still more highly magnified discharging spores.

s, sori;
sp, spores;
spg, sporangia.

they are thus capable of growing immediately into new plants without being united with sperms, we know that they must be **spores** and not eggs, since eggs require fertilization before they will develop. The sacs that contain them are **sporangia,** *spg.* This method of reproduction is therefore evidently an asexual method.

When these spores develop they do not, however, grow into a plant like the original fern, but each grows into a very

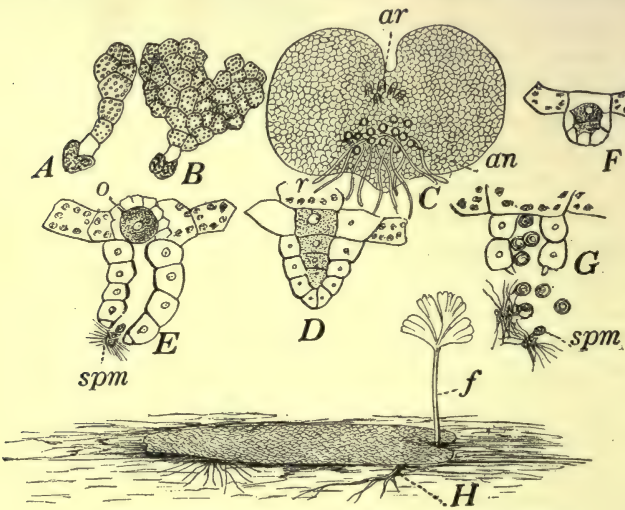

FIG. 125—THE LIFE HISTORY OF THE FERN

A and *B*, sprouting spore; *C*, prothallium full grown; *D*, section of an archegonium; *E*, archegonium at a later stage, showing the ovum, *o*, and the sperm, *spm*, entering to fertilize the ovum; *F*, section of an antheridium at an early stage; *G*, an antheridium at a later stage, discharging sperms; *H*, the young fern, *f*, growing from its prothallium.

small, flat, green leaf (Fig. 125 *A* to *C*), which clings closely to the ground, as shown at *H*, usually not growing to more than one-quarter inch in diameter, and frequently even less. It has no stem, but on the under surface are a few delicate hairs called **rhizoids,** which grow downward, fastening the

plant to the soil and giving it nourishment. It is called a **prothallium** (Lat. *pro* = before + *thallus* = branch) and one would never suspect that this little plant had anything to do with the fern which produced it. We rarely see the prothallia of the fern, not because they are not abundant, but because they are so small and grow so closely to the ground that they do not attract attention. They may be found without much difficulty, however, by carefully searching for them. One of the easiest places to find them is on the outside of the moist earthen flower pots in a greenhouse where ferns are abundant.

After the prothallium has reached its full growth an examination of its under surface with a microscope shows that it in turn is getting ready to carry on a process of reproduction. On the under surface may be found several little projections (Fig. *C*), too small to be visible to the naked eye but clearly made out with the microscope. They are of two kinds, one lying among the rhizoids near one edge of the leaf, *an*, and the other lying near the other edge, some distance from the rhizoids, *ar*. The latter are slightly elongated, with an opening at the free end, and a little canal extending down the middle: they are called **archegonia** (Gr. *arché-* = beginning + *gonos* = birth); Figs. *D* and *E*. At the base of each archegonium is a single **egg,** *o*. The other protuberances, lying near the edge of the leaf among the rhizoids, are called **antheridia** (Gr. *antheros* = flowery); Figs. *F* and *G*. They are more rounded in shape, not so long as the archegonia, and their contents are quite different. Instead of containing a single egg, the whole contents of an antheridium divides up into a large number of parts. Eventually an opening makes its appearance at the end of the antheridium, and these minute bodies emerge and prove to be **sperms,** *spm* (sometimes called **spermatozoids**). The fern prothallium grows only on moist surfaces and clings so closely to the ground that in times of rains or heavy dew its under surface is likely to be covered with water. Each sperm bears a tuft of swimming flagella, which lash to and fro

and enable them to swim in the water, which moistens the under surface of the prothallium. In this moisture they swim in all directions, and some of them come to the mouths of the archegonia. When this occurs there is an attraction between the egg at the bottom of each archegonium and the sperm which has reached its top; the sperm swims to the egg and fuses with it, *i. e., fertilizes it.*

After the egg has been fertilized by the sperm, it is endowed, like any other fertilized egg, with the power of growth. It soon begins to divide, grows rapidly, and develops in the course of time into a little plant which, by continued growth, becomes the fern with which we are familiar and like that with which we started the history; Fig. *H, f.* Thus we see that the common fern grows from a fertilized egg, and that the spore produced by the fern grows, not into a fern at first, but rather into a prothallium.

The life history of the fern is thus an alternation of two different stages and two different methods of reproduction. There is first the fern proper, which, since it produces only spores, is the asexual stage of the plant, and is called the **sporophyte** (Gr. *sporos* + *phyton* = plant). The second stage is the prothallium, which, since it produces eggs and sperms, is the sexual stage. This is called the **gametophyte** (Gr. *gametê* + *phyton*) stage, since it produces gametes. Each of the thousands of spores of the fern is capable of producing a single prothallium. The single egg at the bottom of each archegonium is capable of developing a single fern, and since there are several archegonia on each prothallium, a prothallium is thus theoretically able to produce several ferns. Usually, however, only one of the eggs becomes fertilized by a sperm, therefore only a single fern develops from a prothallium. Sometimes two eggs may grow, and occasionally three may develop, so that two or three little ferns may sometimes be found growing from a single prothallium.

Alternation of Generations in a Flowering Plant.— In a

common flowering plant there is an alternation of generations, based upon the same principle as that just described in the fern; but it is so obscured by certain modifications that it is extremely difficult to understand. The difficulty lies in three facts: (1) *Two kinds of spores* are produced instead of one, as in the fern; one of them becomes the **female gametophyte,** producing the equivalent of the archegonium of the prothallium with its egg, while the other becomes a **male gametophyte,** producing the equivalent of the antheridium of the prothallium with its sperms. (2) Both of these gametophytes have become *very much reduced in size* and are only distinguishable by microscopic examination with special methods. (3) These two gametophytes grow *attached to the plant that produces the spores* instead of detached from it, as does the gametophyte of the fern. If these differences be kept in mind the alternation of generations in the flowering plant is plain. It is as follows: —

We usually speak of the flower as containing sexual organs, the stamens being spoken of as the male and the pistil as the female organs. When the pollen is carried to the pistil it has commonly been spoken of as fertilizing the stigma, the inference being that the pollen is the male cell and actually fertilizes the female cell in the pistil. When the flower is studied by modern methods, however, it is found that in reality it is not a sexual plant at all, and does not produce sexual organs. The stamens are not male organs and the pollen is not a male cell; the pistil itself produces no eggs. The pollen is really a mass of spores, called **microspores.** In the pistil, as already noticed (see Fig. 64), are several ovules and inside of each ovule is a single large cell, formerly called the *embryo sac,* but now known as a **macrospore**; Fig. 126 *sp.* The flower thus produces large numbers of microspores and a smaller number of macrospores, which together correspond to the spores of the fern. These cells are known to be spores rather than gametes, since they do not unite with each other. That the pollen is a spore rather than a sex cell is proved by

the fact that it will grow into a new plant without being united with another cell. The macrospore is also proved to be a spore by the same fact, since it also grows into a new plant without being fertilized. Since the flower-bearing plant thus produces spores instead of eggs and sperms, it is clearly a sporophyte rather than a gametophyte, and it corresponds to the fern frond rather than the fern prothallium. It differs from the fern, however, in that it produces two kinds of spores instead of one. This condition is spoken of as **heterosporous** (Gr. *heteros* = other + *spora*) in distinction from the **homosporous** (Gr. *homos* = alike) condition of the fern.

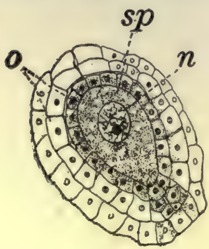

FIG. 126.—MAGNIFIED SECTION OF THE YOUNG OVULE, *o*, OF A FLOWERING PLANT

sp, macrospore; *n*, its nucleus.

If we now try to follow out a comparison between the flower and the fern, we should expect that the flower spores would germinate at once into gametophytes, just as the fern spores germinate into the prothallium, and that the gametophytes would produce the real sex organs with sperms and eggs. Since, however, there are two kinds of spores, we might expect two kinds of gametophytes to grow from them instead of one kind, as in the fern. This actually occurs, only the two gametophytes are very small and rudimentary. The macrospore never gets out of the pistil but, in the midst of the pistil tissue, develops quickly into a tiny growth that represents a gametophyte stage, and this soon produces what corresponds to an archegonium with its egg; Fig. 127. All this occurs early in the life of the flower, before any pollen has been brought to the pistil, and consequently before fertilization can have occurred. It is simply the germination of a spore to form a gametophyte. The pollen, too, goes through its history, growing very slightly but sufficiently, to show that it develops into a gametophyte in its turn. This occurs either before it has left the anther

that produced it, or after it has been carried to the pistil. The growth of the pollen, as well as its resemblance to the gametophyte, is so slight that it was not recognized for years after plants had been carefully studied But it is now known that the pollen does, at least in some of the higher plants, develop sufficiently to show the gametophyte stage and then produces what corresponds to antheridia; Fig. 128 *g*. The pollen tube which grows down through the style of the pistil (Figs. 65 and 127 *pt*), in a way corresponds to the antheridium; and inside it are small cells, or nuclei of cells, *m*, that correspond to and have the same function as sperms. In other words, the pollen does not correspond to a sperm, but is simply a spore that grows into a male gametophyte, which itself produces the equivalent of sperms.

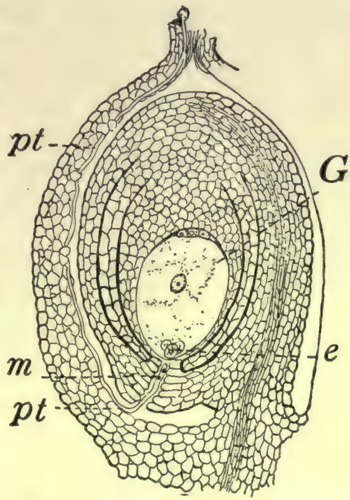

FIG. 127.—A SECTION OF AN OVULE AFTER THE SPORE HAS GROWN INTO THE FEMALE GAMETOPHYTE

G, the gametophyte; *e*, egg; *pt*, a pollen tube pushing its way through the style to fertilize the egg; *m*, is the male nucleus in the pollen which corresponds to the sperm and fertilizes the egg.

It is thus seen that inside of the pistil one kind of spore grows into a female gametophyte and produces eggs, while on the stigma the other kind of spore grows into a rudimentary male gametophyte and produces the equivalents of sperms.

Following farther the comparison with a fern, the next step is the fertilization of the egg of the female gametophyte by the sperm of the male gametophyte. In the flower this fusion is accomplished as follows: The pollen tube (Fig. 128 *E*) is an outgrowth from the male gametophyte, and pushes its way

down the style until it reaches the ovule at the bottom of the ovary; see Figs. 65 and 127 *pt.* In this ovule the female gametophyte has formed, and has by this time produced what corresponds to archegonia with their eggs; Fig. 127 *e.* The tip of the pollen tube approaches the egg and finally comes in contact with it. Inside of the pollen tube are nuclei which represent the sperms; Fig. 127 *m.* As we have noticed on page 257, when the fertilization of an egg occurs it is only the nuclei of the cells that fuse, so that the nuclei in the pollen

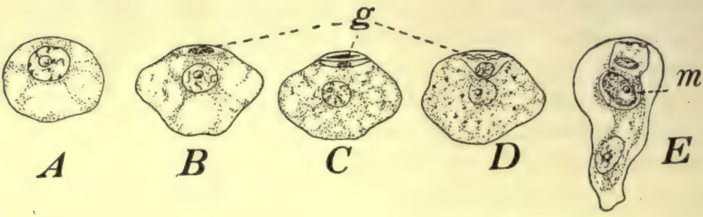

FIG. 128.— DEVELOPMENT OF THE POLLEN

A, a single pollen grain or microspore; *B*, the cell divided into two; *C*, the pollen, which has produced a rudimentary gametophyte at *g*; *D*, a later stage with the gametophyte *g* still more rudimentary; *E*, the pollen developing the pollen tube. The nucleus *m* divides later into two nuclei representing sperms.

tube represent all of the important parts of a sperm. When the pollen tube comes in contact with the egg it allows these nuclei to escape into the egg, where one of them fuses with the nucleus of the egg, thus producing the actual sex union.

The fertilized egg is now endowed with powers of growth and begins at once to develop into a new plant. Again following the comparison with the fern, we shall expect that the plant which comes from the fertilized egg must be the sporophyte, which in this case is, of course, the plant that produces the flowers. The egg develops at once, growing quickly into a tiny plant with a stem and one or two leaves. This occurs while the egg is still retained in the ovary of the flower that produced the spores. After a time this plant stops growing

and becomes surrounded by a hard shell, inside of which it remains dormant for an indefinite period. This forms the seed, which thus appears to be a little sporophyte surrounded by a shell, and it remains dormant until later when it can be placed under proper conditions for germination; Fig. 66. It develops its spores, of course, after it has grown large enough to produce flowers.

It is thus seen that the flowering plant has an alternation of generations as truly as does the fern, only in the flowering plant the sex stage, the gametophyte, is very small, while the asexual stage is very large. The plant with which we are familiar is in the sporophyte stage, and the pollen and the single cell inside its ovule are its spores. These develop into tiny growths that correspond to the gametophytes and are developed within, or attached to, the sporophyte that produced the spores, *i. e.*, in the ovary or attached to the stigma. But tiny as they are, they produce the equivalents of eggs and sperms, which subsequently fuse by true fertilization. The real fertilization of the plant, then, is the fusion of the male cell contained in the pollen tube with the egg contained in the ovule. The term fertilization, which has been commonly applied to the transfer of the pollen to the stigma, is a misnomer, and is largely given up, the term **pollination** being substituted instead.

Alternation of Generations among Animals.— An alternation of generations also occurs in the animals known as hydroids, animals related to the *Hydra*. The fresh-water *Hydra*, as described in Chapter VII, multiplies by budding; but as fast as the buds are produced they break away from the original animal and become independent. In the marine *Podocoryne*, the buds do not break away but remain attached to form a colony, made up of large numbers of individuals; Fig. 129. The individuals are partially independent of each other and if broken apart are capable of living independent lives. This stage of the life of the animal, since it has an asexual multi-

plication by budding, is the *asexual stage,* and is comparable to the asexual stage of the fern above described (the fern proper). It differs from the fern, however, in the fact that it does not produce new individuals by spores, but by budding.

After a colony reaches a certain stage in its growth, some buds arise which differ in shape from the others. These (Fig. 129 *gb*) are rounded, and eventually break away from the

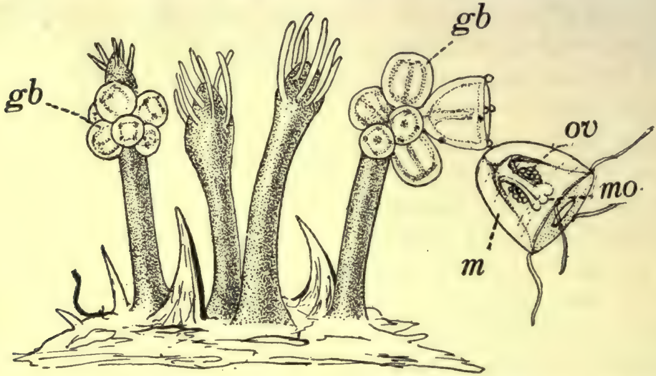

FIG. 129.—A COLONY OF HYDROIDS (*PODOCORYNE*), SHOWING AN ALTERNATION OF GENERATIONS

The feeding animals have tentacles; *gb*, the generative buds, which eventually break away and become medusæ; *m*, medusa; *mo*, mouth of the jellyfish; *ov*, ovaries.

colony and assume an independent existence. These free buds now become bell-shaped individuals of clear, transparent jelly, and are known as **jellyfishes** or **medusæ,** *m.* The jellyfishes have muscles which enable them to swim and travel for long distances in the ocean. As they have a mouth and digestive cavity they can procure their own food, and grow, frequently attaining considerable size after separating from the original colonies; some species, indeed, assume a size very much larger than the animal that produced them. After having lived this free life for a time, each becomes sexually mature, developing sexual glands, either *ovaries* or *spermaries;* Fig. 130 *g.* The sex bodies become mature, and are extruded into the water,

where they float around until the eggs and the sperms come in contact and fuse, producing a typical fertilization. The jellyfish itself, after it has extruded the sex bodies, has no further function, and dies. The egg, however, now grows into a new colony like the original. This jellyfish is evidently the *sexual stage* in the development of the hydroid, and corresponds to the sexual stage in the development of the fern (the prothallium).

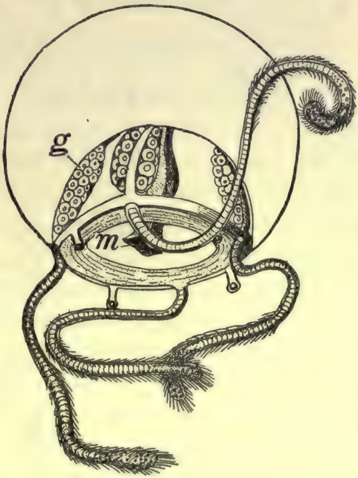

FIG. 130.— A FULL-GROWN JELLYFISH
m, mouth; *g*, gonads.

The alternation of a sexual with a non-sexual method is far more common among plants than among animals. It is developed in all plants except the lower orders, even the flowering plants, as we have just seen, having such an alternation. Among animals, however, alternation of generations is found only in the lower orders. It is common among the *Hydroids*, and a modified form of it occurs in one of the higher animals (*Salpa*); but among the great majority of animals, when sexual reproduction is developed, the non-sexual method is totally lost.

CHAPTER XIV

DEVELOPMENT OF THE FERTILIZED EGG

EMBRYOLOGY AND METAMORPHOSIS

By the term **embryology** is meant that part of the life history of the animal or plant which begins with the fertilization of the egg and continues up to the time when a developed animal is formed, ready to emerge from the egg as a free-living, independent individual. When it hatches from the egg it is sometimes like the adult, except in size; but sometimes it is unlike its parents and goes through a further series of changes. In this case we speak of these later stages as constituting the **larval history** or a **metamorphosis** (Gr. *meta* = beyond + *morphé* = form). The development of animals from the egg to the adult stage, embryology and metamorphosis, has proved to be an especially interesting phase of biological study, and has received much attention in the last fifty years. The embryology of different animals and plants differs widely, but certain fundamental laws and rules are found to apply to all alike. In this introductory study it is only possible to give a few of the fundamental principles, using a single animal as an illustration. For this purpose will be described the development of the frog, which, although peculiar in some respects, will illustrate the important laws both of embryology and metamorphosis. The embryology of plants has also been studied rather extensively, but has not hitherto yielded so many interesting lessons as the embryology of animals.

EMBRYOLOGY OF THE FROG

1. **Segmentation.**— The life of an individual frog may be said to begin the instant that the nucleus of the egg fuses with the head of the sperm (Fig. 121 *H*), the time of fertilization being thus a starting point of a new life. This fertilization of

an egg nucleus seems to endow it with renewed power. The nucleus of the egg previous to fertilization has lost its power of division, and if left to itself, eventually dies and disappears; but after fusing with the sperm the combined nucleus shows a reinvigorated power of growth. It begins almost at once to divide in two parts (Fig. 132 *A*); the process of the division of the nucleus followed by the division of the cell is identical with that described on page 85. As a result of this division there are produced two cells, each with a centrosome, each with its nucleus, which contains the same number of chromosomes as the fertilized egg nucleus. Moreover, at the beginning of the division, each chromosome is split lengthwise, and half of each chromosome passes into each of the two nuclei of the two new cells. Each of the two cells thus contains chromatin material from each of the chromosomes of the fertilized egg, and since these chromosomes come partly from the male and partly from the female parent, it follows that one-half of the chromatin in each cell is derived from the male, and one-half from the female parent. Hence, each cell will contain inherited traits from each parent. This first division of the egg is soon followed by a second, which produces four cells, and in this division the same process is repeated, the chromatin material being again split up so that each of the four cells (Fig. 132 *A*) contains chromatin material from both parents. This process now goes on, the cells dividing again and again, until the original egg has divided into a large number of small cells, each cell probably containing chromatin material from both parents. This process of **segmentation** or **cleavage** is the first step by which all animals and plants begin their life history, the egg in all cases dividing after a similar manner into a large number of cells.

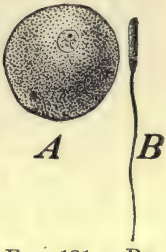

FIG. 131.—REPRODUCTIVE CELLS OF FROG

A, egg; *B*, the sperm.

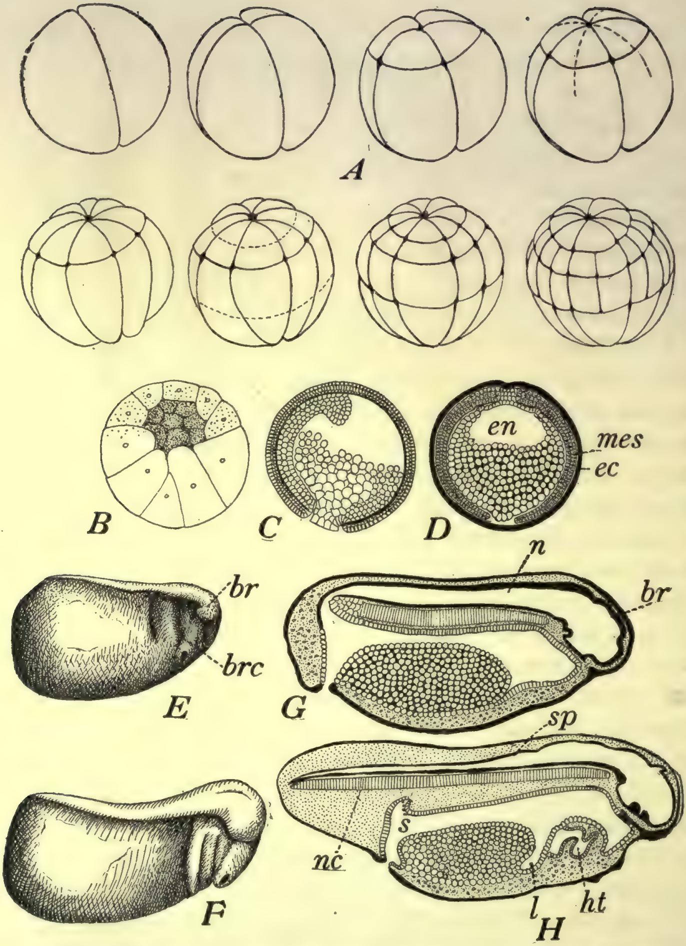

FIG. 132. — DIAGRAM REPRESENTING THE DEVELOPMENT OF THE FROG

A, eight stages of the segmentation of the egg; *B*, section of the egg showing the beginning of the differentiation of ectoderm from endoderm; *C*, sections at a later stage, showing the growth of the ectoderm over the endoderm; *D*, section after the germ layers are formed; *ec*, ectoderm; *en*, endoderm; *mes*, mesoderm; *E*, surface view of a young embryo showing two branchial slits, *brc;* *F*, surface view of an older embryo; *G*, diagrammatic, longitudinal sections of the stage *F;* *H*, a later stage. In these diagrams the ectoderm is in black, mesoderm, with dotted shading, and endoderm without shading.

br, the brain; *l*, liver; *nc*, notocord; *sp*, spinal cord.
ht, heart; *n*, nervous system; *s*, sexual duct;

(Various authors.)

2. **Differentiation.**— Although the cells at the outset are much alike, they soon begin to show differentiation. In Figure 132 *B* it will be seen that the upper cells are smaller than the lower ones, and the contents of the larger cells are quite different from those of the smaller. The difference thus shown early in the development of the egg marks the distinction between those cells which will eventually form the alimentary canal and those which will form the other parts of the body. As the development goes on and the number of cells in the embryo increases more and more, greater and greater differences are found among them (Figs. *C* and *D*), so that one group of cells after another becomes set apart by differences in structure and functions, until finally, when the animal has reached the adult form, it is not only composed of innumerable cells, but these cells have assumed a great variety of shape and function. This process of gradual change of shape and function of cells which were originally alike, is spoken of under the name of **differentiation.** A similar change occurs in all multicellular animals and plants; for, after segmentation of the egg, there always follows a differentiation of cells.

3. **The Formation of Germ Layers.**— After the cells have multiplied until they have become quite numerous, they begin to arrange themselves in three groups. Soon there appears an outer layer, an inner layer, and a middle layer, known respectively as **ectoderm, endoderm,** and **mesoderm.** These are shown in Figure 132 *D*, which represents a later development in the frog. The method by which these three layers are formed is shown diagrammatically in Figure *C*. It may briefly be described as the growing of the mass of the smaller, ectoderm cells, around and over the larger, endoderm cells, so as finally to bring the larger cells upon the inside of the embryo, surrounded by the smaller ones. Meantime there has grown from the outer and inner layers a third mass of cells, the mesoderm, that pushes its way between the other two, thus partly filling up the space between the outer and inner layers; Fig. *D*. The

final result is that the embryo has an ectoderm of smaller cells on the outer side, an endoderm of larger cells on the inner side, and a mesoderm between the outer and the inner layer. These three layers of cells remain distinct, and are destined for different purposes in the subsequent life of the animal, each one of them developing into certain organs only. The organs that are developed from the three layers are as follows: —

The mesoderm.— From the mesoderm develop the *muscles*, the *bones*, the *heart*, and the *blood vessels*, the *lining* of the *body cavity*, the *outer layer* of the *alimentary canal*, the *mesentery* which holds the alimentary canal in position, and the *reproductive system.*

The endoderm.— From the endoderm develop the *alimentary canal*, the *glands* around the mouth, the *lungs*, the *pancreas*, and the *liver*. The muscles which form the wall of the alimentary canal are developed from the mesoderm, but the *lining of the digestive tract*, with all its *glands*, which secrete the digestive juices, is formed from the endoderm.

The ectoderm.— The ectoderm gives rise to the *skin*, including the epidermis and the dermis. It also grows inward to *line the mouth* and the extreme *posterior end* of the alimentary canal. The ectoderm also gives rise to the *nervous system*, with all of its parts, including the brain, the spinal cord, the nerves, and all of the *sensory organs*, like the eyes, the ears, organs of smell and touch.

It will be seen that the alimentary canal is made of three parts: the anterior end is formed by the infolding (*invagination*) of the ectoderm, the infolded part forming the mouth or **buccal cavity**; the posterior end is also formed by an invagination of the ectoderm, which forms the **cloacal chamber**; the rest of the canal is formed from the endoderm. These three parts are called the **foregut** (*stomodæum*), the **midgut** (*mesenteron*), and the **hindgut** (*proctodæum*). Similar relations are found in other vertebrates and also in the lower animals as well.

Layers similar to those described are found in the embryos

of nearly all animals. Among some of the very lowest (*Hydra*) only the ectoderm and the endoderm are formed, the mesoderm being omitted. But in all except the lowest types three layers are formed early in the embryological history. The method by which these three layers are formed differs in different animals. In Figure 15 is shown a method of formation of the endoderm, differing from that of the frog, by an infolding of a hollow sphere to form a double sac. But however differently the layers are formed, the system of organs which are developed from them is essentially the same. The nervous system is always developed from the ectoderm, the alimentary canal from the endoderm, and the blood system and muscles are developed from the mesoderm.

4. **The Formation of the Body.**— While the germ layers have been forming, the embryo has been elongating (Fig. 132*E*), and the endoderm forms itself into a hollow tube within the body, which acquires an opening, first at one extremity and then at the other; Fig. *G*. This tube becomes the **alimentary canal,** and the two openings are the **mouth** and the **anal,** or **cloacal opening.** Between this inner tube and the outer wall of the body lies a cavity, more or less filled with the mesoderm, but in it eventually appears the **body cavity** or **cœlum,** which becomes a more distinct cavity as the animal grows. Early in the development, when the animal has assumed the form shown at *E*, openings in the side of the neck break through from the alimentary canal to the exterior. There are at first two of these, shown at *E*, *brc*, but later others appear. These are known as **branchial openings,** and become passages through which water taken in at the mouth may be passed to the exterior. They represent the gill slits present in fishes, and are to have a similar function a little later, when the frog hatches from the egg and lives in the water. While these changes are going on there is formed a long, thickened rod of ectoderm in the middle line of the back, extending from one end of the animal to the other, which is the beginning of the nervous system;

Fig. *G*, *n*. The result is the formation of a little animal such as is shown in Figure *H*, in which the relation to the adult structure can be clearly seen, although at this stage the embryo only slightly resembles the adult frog. The development that has taken place up to this point has occupied a period of several days from the time when the egg was fertilized, the exact length of time depending to a large extent upon the temperature, the different stages being more rapidly passed through if the eggs are kept warm than when they are kept cool.

Various other systems of organs begin to appear at this stage or a little later. From the ectoderm along the middle line in the back, develops a rod of nervous matter, and around the front end of this, outgrowths appear, which become the *eyes*, *ears*, and other *sense organs*. The nervous mass itself differentiates into the *brain* and *spinal cord;* Fig. *H*. The endodermal tube also develops outgrowths which in time become the *lungs*, *liver*, and *pancreas*. One part of the mesoderm forms itself into a gelatinous rod running lengthwise in the back of the embryo, just beneath the nervous system. This is the **notocord,** *nc;* it represents the beginning of the spinal column, and in time the *vertebræ* grow around it. Another part of the mesoderm develops into the *heart*, *ht*, and *blood vessels;* while that part of it which lines the body wall becomes the *muscles*, and that which is next to the intestine develops into the *peritoneum* and *mesentery*. From the mesoderm, too, the *kidneys* and *sexual glands* arise, with their ducts, *s*.

These changes take place quite rapidly, although they are not completed for many days. When they are finished the whole series of the organs of the frog is present, though yet incompletely developed. Meantime the animal has hatched from the egg, and forces its way out of the jelly in which it has been embedded and assumes an independent life.

5. **Metamorphosis.**— The further development of the frog comprises a number of different stages, shown in Figure 133, the important features of which are as follows: The animal

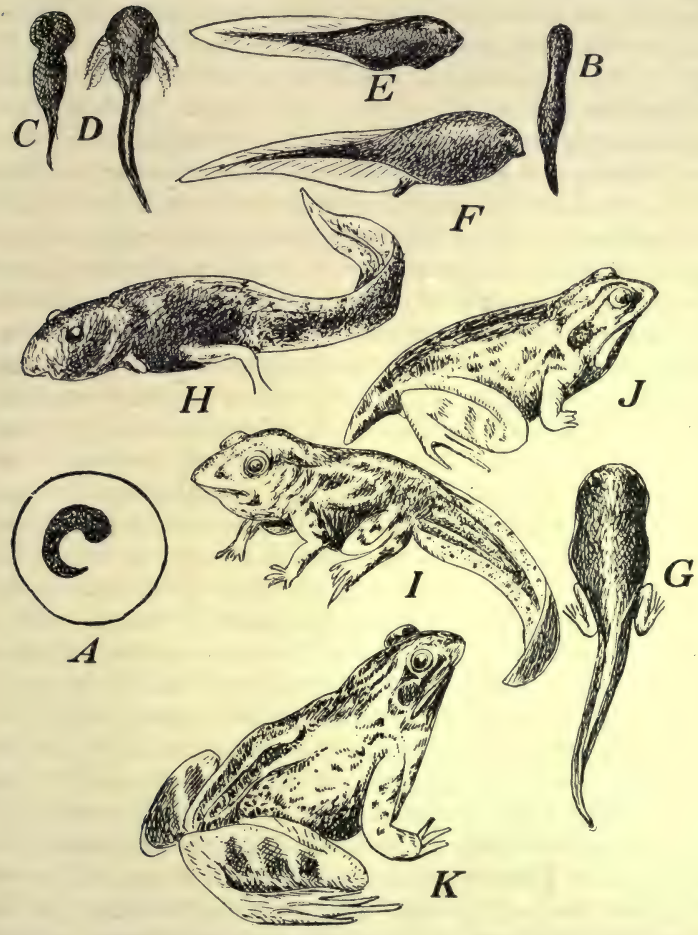

FIG. 133.—THE METAMORPHOSIS OF THE FROG

A, the embryo within the egg; *C*, at the time of hatching. At about the stage *I*, the animal leaves the water and lives a part of the time in the air.

elongates, and a slight constriction appears behind the anterior end resembling a neck. The front portion is, however, not the head alone, but the head and body fused together, while the back portion soon grows out into an elongated tail. From the side of the two branchial openings feather-like external **gills** or **branchiæ** develop, which, projecting laterally from the head, serve as respiratory organs; Fig. *D*. The free larva is now known as a **tadpole,** and from this time it is obliged to depend upon itself. Its digestive organs have become developed enough to perform their functions, and the larva begins to feed upon vegetable food, eating the delicate green plants that are found growing on the bottom of the pool where the larva attaches itself. The rapidity with which the animal goes through the subsequent changes is dependent chiefly upon the amount of food it obtains, and the temperature; but it soon begins to pass through the stages represented in Figures *C* to *G*. The front end of the body, which is the head and body fused together, increases in size and becomes rounded, while the tail elongates and becomes flatter, serving as a swimming fin. The external gills disappear; but the gill slits remain, the animal still breathing by the use of internal gills, not visible from the outside. The size of the tadpole varies with the different species of the frog; in some of the ordinary frogs it may become two or even three inches in length, while in other species it is not more than half an inch.

The next change is the appearance of a pair of small protuberances, or buds, on the posterior end of the body on either side; Fig. 133 *F*. These grow rapidly in length and develop into the **hind legs.** A similar pair of buds appears at the anterior end of the body, a little behind the gill slits, which later grow into the **fore legs** or arms. As these legs and arms grow, the whole shape of the body changes; the **eyes** appear on the sides of the head; the mouth, which is at first a round sucking slit, elongates into a large slit surrounded by the jaws; the head assumes more of its final form; the shape of the body changes from the rounded tadpole to a more elongated structure.

The tail also shortens until it disappears. It does not drop off, but is gradually absorbed into the blood vessels and carried to the rest of the body, where it is used as nourishment for the other parts of the body. These changes are not abrupt but take place gradually as the animal assumes the adult form; Fig. 133, *F* to *K*.

By the time the form shown in Figure *J* is reached, the gill slits have entirely closed, the skin growing over them; and from this time on the animal takes air into its mouth and forces it into its lungs in the ordinary fashion of the adult frog. It changes, therefore, from a water-breathing to an air-breathing animal. But even when it is an adult, the animal never quite loses its power of respiring by means of water, for the skin of the adult frog is always kept moist, and contains abundant blood vessels by means of which oxygen can be absorbed from the water, and carbon dioxid excreted. Not until the gill slits have closed and the lungs have become functional is the frog able to leave the water and live in the air. By this time its legs have become well grown and are strong enough to enable it to move more or less vigorously on the land, so that the tadpole may leave the water and assume its adult habits.

Other Types of Metamorphosis.— Such a series of changes from the embryo to the adult is known as metamorphosis. Many other animals besides the frog have a metamorphosis. One of the best-known examples is the metamorphosis of a butterfly, which hatches as a **caterpillar,** lives a considerable part of its life in this stage, and then passes into a **pupa** inside of a cocoon. Here it remains dormant for a considerable time and eventually emerges in the form of a winged butterfly, the **imago.** Many other types of metamorphosis are found among animals, for it is quite common for them to pass through a series of stages in their development, each stage being different from the other, and each different from the adult. Not all animals, however, have a metamorphosis, many passing by a very direct course to the adult stage. In the ordinary chick,

for example, the embryo pursues the most direct course possible for building itself from the simple egg to the adult, and the chick, when it hatches from the egg, is practically adult in form, although not in size. In such cases we call the history a **direct development,** in contrast to an **indirect development** or a metamorphosis.

Embryology a Repetition of Past History.— It will be seen from the development of the frog that at one period it resembles a fish in a number of points. It lives in the water, has a flat swimming tail, possesses branchial slits, and carries on respiration by means of gills. The study of geology has shown that in the history of the world fishes preceded frogs, and it is thus seen that in its embryology a frog shows a tendency to repeat the past history of animals. Such a repetition is found, not only in the frog but in many other animals, for it is a fundamental biological law that embryology repeats past history. In technical terms this is expressed by the statement that **ontogeny** is a repetition of **phylogeny,** ontogeny (Gr. *on* = being + *-geneia*) being the individual's embryological history, and phylogeny (Gr. *phylon* = tribe + *-geneia* = producing) the history of the race, during the geological ages. This parallel has been one of the strong arguments which have convinced scientists that our present forms have been derived by ordinary methods of descent, through the process of reproduction, from the earlier inhabitants of the world; or, in other words, that the history of the organic world has been one of evolution and not one of special creation of each species independently, as was formerly believed. While a few years ago this law of repetition was thought to be more strictly adhered to than careful study has proved to be the case, the general fact that embryology tends to repeat past history remains as one of the interesting and significant laws of nature. It is sometimes called the **biogenetic law.**

Oviparous and Viviparous Animals.— Many animals (for example, the frog) extrude their eggs into the water as soon as they are mature and take no further care of them. In some cases,

as in birds, snakes, etc., the eggs, after being laid, are still cared for by the parents, and may be incubated by the parents to keep them warm during their development. All animals that thus lay eggs are called **oviparous** (Lat. *ovum* = egg + *parere* = to bear). A few of the higher animals, like the mammals, retain the egg for some time within the body of the mother. The sperms from the male in these animals are carried into the oviduct at copulation by the **penis,** and the eggs are fertilized while they are still within the oviduct. After the egg is fertilized it attaches itself to the part of the oviduct called the **uterus,** and here undergoes development. The developing embryo, called the **fœtus,** is nourished through the maternal blood vessels, and grows to a considerable size while still retained in the uterus and attached to it by a membrane called the **placenta.** Eventually, when it has become mature, it is detached from the uterus and expelled to the exterior at **birth.** The young are well developed at birth, and such animals are spoken of as **viviparous** (Lat. *vivus* = alive + *parere* = to bear).

CHAPTER XV

THE SOURCE AND NATURE OF VITAL ENERGY

MATTER AND ENERGY

Physical science teaches that the universe consists of two great factors, matter and energy.

MATTER

By **matter** is meant the substance of the objects found in nature, such as earth, stones, etc. One of the fundamental laws of physics is that, while matter may be changed from one form to another, it can neither be created nor destroyed. The amount of matter in the universe at the present time is thus exactly the same as it has been in all previous ages.

ENERGY

By **energy** is meant the force or power that exists in nature. *Energy is the power of doing work,* and may best be explained by illustrations.

Active Energy.— A cannon ball flying through the air is said to possess energy. It is flying with such force and momentum that it requires great resistance to stop it; and if the ball could be received upon properly devised machinery, its motion might be made to turn wheels or do any other kind of work. The revolving flywheel of an engine also possesses energy of the same type, its motion and its great momentum enabling it, if connected with machines, to move them and make them do work. In the same way, any form of motion is energy. In another type of energy the motion is not so evident. Heat, liberated from burning coal, is energy, since, when it is properly applied to an engine, it may be made to do work. In this case the heat may be applied to water, which it vaporizes into steam, and this eventually may produce motion in an engine; but it

is fundamentally the power in the heat that goes into the engine and finally exhibits itself in the motion. In the same way, the electric current, flashing along the electric wire, is energy, since this also, if received by a proper machine, can be made to set machinery in motion and thus accomplish work. Each of these four examples of force clearly comes under the definition given, since they all show the power of doing work. They also have another common characteristic: they all represent motion. The cannon ball and the flywheel are evidently in motion, and the physicist has shown that heat and electricity are also forms of motion. Each of these four examples, then, represents energy in action. An indefinite number of other examples of this same type could be given, for all forms of light, heat, motion, chemical action, and electricity are examples of energy, and, in one form or another, all represent energy in motion. This general type of energy in motion is **active energy** or **kinetic energy** (Gr. *kinetos* = moving).

Passive or Potential Energy.— Energy is not always active but, under some circumstances, it assumes a dormant form, which we speak of as **potential energy.** By the term "potential" is meant that the energy, though not at the moment active, may at any time be converted into active energy. For example, a heavy stone, poised on the roof of a house, is at rest, exhibiting no active energy; but it has potential energy, in virtue of the fact that it is raised some distance above the ground. The moment it is dislodged it begins to move, falling to the ground by the law of gravitation, and as it falls it develops the energy of motion. No energy is put into the stone by simply dislodging it from its position on the roof; hence it follows that the stone contained the energy when it rested upon the roof, only the energy was in a dormant or potential form. When it was dislodged from its position the potential energy began to be active, and when the stone reached the earth it became quiet again, its energy having apparently disappeared.

A different type of potential energy is illustrated by a bit of ordinary coal. The coal that is put into a furnace contains, stored within itself, a large amount of energy in a dormant form. That it contains the energy is perfectly evident from the fact that we need only put it under proper conditions, by kindling it, and the energy will be liberated from the coal in the form of heat, which may be converted into motion by an engine. We can get no motion out of the steam engine unless we put the energy into the furnace in the form of coal, wood, or other fuel. Evidently fuels may be looked upon as containing a store of dormant energy. These types of passive energy, which exhibit no action, but which are capable of being brought into activity when placed in the right conditions, are spoken of as **potential energy** or **energy of position.**

THE CONSERVATION OF ENERGY

Energy can neither be created nor destroyed. Just as we cannot destroy nor create matter, so we cannot destroy nor create energy, the amount of energy present in our universe to-day being the same as it has been in all previous time. This statement does not seem quite so self-evident as the statement that matter cannot be created or destroyed, for many examples occur that, at first sight, seem to be instances of the destruction of energy. A stone which has been dislodged from its position upon the roof falls rapidly to the ground and develops energy in falling, but on reaching the ground it stops suddenly and its energy seems to have disappeared. When a cannon ball strikes a ledge of rock it suddenly stops. Any examples of the stopping of motion would seem to be illustrations of the destruction of energy.

A careful examination, however, shows that in these cases there is in reality, no destruction of energy, but simply the conversion of one form of energy into another. In the case of the stone lodged on the roof, it is evident that at one time a certain amount of energy must have been used to lift this stone

into its position, and when the stone fell it only redeveloped the energy that was originally required to lift it to its position. The amount of energy required to lift the stone to its position is exactly the same as that which is developed by the stone when it falls to the ground, and the lifting of the stone and its falling illustrates the conversion of active into potential energy and reconversion of potential energy into an equivalent amount of active energy. It would seem, however, that when the stone reaches the ground the energy disappears. But if we examine the fallen stone carefully, and the earth underneath it, we find that both have been warmed. The moment that the motion of the stone ceased, heat appeared. Heat is a form of energy, and thus, when the stone comes to rest on the ground, the motion of the stone is converted into that form of energy which is called heat. This heat is soon dissipated from the stone and from the earth, for they presently resume their former temperature. The heat has simply gone off into the air; it is not destroyed but has simply distributed itself, and slightly raised the temperature of the air. Nowhere in this series of changes has there been any loss of energy, but simply the conversion of one form into another. Some 5000 years ago the Egyptians lifted a large number of stones and placed them one on top of another so as to make the pyramids, exerting a large amount of energy; the energy used in placing the stones in position was stored away in the pyramids in the form of potential energy and is there still. If at any time the pyramids should topple over and the stones fall to the ground, there would be redeveloped an amount of motion exactly equal to the amount used to lift them in position. Thus energy may be stored away and remain in a potential form for ages; but at any future time the energy originally stored away may reappear in the form of active energy.

The energy present in a dormant form in coal requires a little more explanation. Chemists have shown that the smallest particles of matter which we can see are themselves made of

much smaller particles called *atoms*, which are quite invisible even with the highest-power microscope. They also tell us that these atoms are united in groups, which are called *molecules*, each consisting of a number of atoms. Just as it requires the expenditure of energy to lift stones into position to form a monument, it also requires energy to lift atoms into position to form a molecule; and if the molecule is broken down, the energy is liberated according to the same principle concerned in liberating it when a monument falls. If, therefore, we look upon the particle of coal as a series of molecules, each built up of many atoms, it follows that if these tiny molecules are broken down, so that their atoms will assume a simpler form, the energy imprisoned in them, in a dormant state, will be released. Coal is thus made of immense numbers of complex molecules, each of which has been built by the expenditure of energy, and the coal contains, in a potential form, energy which may be released by breaking up the coal. The molecule is broken down when the coal is burned and its energy appears in the form of heat, which may then be applied to the moving of an engine. This of course raises the question as to how the energy was stored away in the coal,— a question to which we will refer later.

THE TRANSFORMATION OF ENERGY

Any type of energy may be converted into any other type. When we lift a stone to the roof of the house we convert energy of motion into energy of position, and when the stone falls, energy of position is converted again into energy of motion. When it is halfway to the ground, it has a certain amount of energy of *motion*, because it is moving; but it also has a certain amount of energy of *position*, because it is considerably above the surface of the earth. The more closely it approaches the earth, however, the more its energy of position is converted into energy of motion, and the moment it strikes the ground, all of its energy of motion is converted into heat. The potential

energy in the coal in the furnace is converted into heat; the heat is converted by the engine into motion; the motion of the fly-wheel, by being attached to a dynamo, may be converted into electricity; the electricity, passing over the wires, may run into an electric lamp, where it is converted into light, or it may go into an electric stove to be converted into heat. The motion of water over a waterfall may easily be converted into the motion of a wheel by the means of a water-wheel, this into electricity, and this in turn into light, heat, motion, or any other form of energy that we wish to obtain.

Some of the types of transformation of energy are more easy to bring about than others. It is much easier to convert motion into heat than to convert heat into motion. Any form of motion is sure to take the form of heat eventually, whether we are turning a grindstone or putting a brake on a railroad train, or whether a cannon ball is stopped by a stone cliff. Heat, indeed, seems to be the type which all forms of energy have a tendency to assume in the end; it is then radiated into the atmosphere and into space, where it is beyond the reach of this earth and is called **radiant heat.** It is true that we have some devices by which heat may be reconverted into motion, but always with considerable loss as radiant heat. We put into our steam engines five times as much stored energy in the form of coal as we receive in return in the form of motion, not because the energy is destroyed, but because four-fifths of the energy of the coal is wasted in heating the machinery and the air, and then passes away as radiant heat, only a small part being converted into motion.

Definition of a Machine.— A **machine** is any device which converts one form of energy into another. The locomotive is a machine for converting heat into motion; the electric bulb is a machine for converting electricity into light; the motor converts electricity into motion. Even the gas burner is a machine for converting the chemical energy of the gas into light. A clock is a machine which converts the potential

energy in its coiled spring into the motion of its pendulum and hands; a sailboat is a machine for converting the energy of the wind into the motion of the boat. So one might illustrate indefinitely. In no case is there any creation of energy by the machine, simply the conversion of one form into another. Not only is there no creation of energy, but there is an actual loss of available energy, inasmuch as heat always develops, and after energy has assumed the form of heat, as we have just seen, it is difficult to get it back into another form. While there is no actual destruction of energy when it is converted into heat, there is, in every form of machinery with which we are acquainted, a loss of *available* energy. Sometimes this loss is very great. For example, in an ordinary electric lamp about 95% of the electrical energy that is put into the bulb is lost; only 5% of it appears as light. The efficiency of a machine is indicated by the percentage of the energy supplied which we can get back in the form that we desire. Machines differ much in their efficiency in this respect. It is quite easy to get very efficient machines for converting motion into heat, but very difficult to get an efficient machine for converting heat into motion. The most efficient machines that we have for this latter purpose are gas engines, some of which give back 25% or 30% of the energy put into them. Most engines give a far smaller proportion than this. Many steam engines give back as motion not more than 5% to 10% of the energy furnished. This matter of efficiency is one of interest as we come to study the power of living organisms to convert one type of energy into another.

THE LIVING ORGANISM AS A MACHINE

From the definition above given it is very easy to see that the living organism, either animal or plant, is a machine, since it is a mechanism which transforms one type of energy into another. This may best be understood by considering first the life of plants and then that of animals.

THE LIFE OF A PLANT

Sunlight furnishes the earth with practically all its energy. There have been many attempts to make efficient sun engines, which will utilize the rays of the sun to serve directly as a source of energy sufficient to run engines. Sun engines have been made, but as yet they are cumbersome, unwieldy, and impractical. But it seems that the time must come, after the exhaustion of the coal supply, when sun engines will be a necessity. A plant growing on the surface of the earth is a perfectly efficient sun engine, devised by nature to utilize the rays of the sun and then to transfer the energy thus received to the rest of the living world. The life of the ordinary green plants consists of two features: (1) the utilization of the sun's rays and the storing away of these rays in a form of potential energy; (2) the liberation of this energy and its subsequent use by the plant. These two processes will be considered in turn.

Energy Stored by Plants.— All green plants have the power of absorbing the sun's rays and, by the means of energy thus obtained, of building up chemical compounds of great complexity which will contain the energy thus absorbed, stored away in a potential form. Their method of accomplishing this is in part as follows: In Chapter VI we have learned that plants have the power of manufacturing starch out of carbon dioxid and water. This process involves the manufacture of complex molecules ($C_6H_{10}O_5$) out of simple ones (H_2O and CO_2), and hence requires the expenditure of energy. Since it can take place only in sunlight, it becomes evident that (1) the sun's rays are the source of energy used, that (2) the starch manufactured will contain in a potential form the energy used in building it, and that (3) this energy may be liberated in an active form if the starch molecule is broken down.

Stored Energy Utilized by Plants.— The energy stored in the starch is the primary source of energy for nearly all the activities on the earth, except water power. The plant uses it for two distinct purposes: 1. While plants do not in their

ordinary life exhibit a great amount of active energy, they do develop a little heat and a little motion, and they are constantly lifting quantities of water from the soil to the tops of the branches. All this requires energy, which is obtained by breaking down some of the starch and utilizing the energy thus liberated. 2. Plants are always at work building other materials besides starch. *Proteids, woods,* and *fats* are manufactured by combining, within the living cells, the various materials absorbed by the roots (nitrates, etc.), with the starches made in the leaves. The chemical processes by which these new organic compounds are built are not yet understood, but one feature is significant. Just as starches are more complex than the water and carbon dioxid out of which they are made, so the proteids are far more complex than the starches, nitrates, etc., out of which they are made. Since it requires energy to build the complex molecule starch out of the simpler carbon dioxid and water, so too it requires energy to build proteids out of the starches and nitrates. For this purpose the plants do not use the sun's rays directly, but they use the energy they have stored in the starch. In other words, in making proteids, a certain quantity of starch or sugar is broken down into a condition of carbon dioxid and water, and as a result of this destruction the stored energy in the sugar molecule is liberated. This energy is liberated within the living cells, and under such conditions the protoplasm can make use of it for building the complex proteids out of the simpler materials. This general process is called **metastasis.**

Thus it is seen that the plant protoplasm uses the starches for a double purpose. Part of them are reduced to the condition of carbon dioxid and water in order to liberate the energy needed by the plant. Part of them are combined with other ingredients to enter into the combination of proteids, etc. By this latter process there is thus (1) an accumulation of proteids and other substances in the plant body, (2) a destruction of sugar or starch, (3) an elimination of carbon dioxid and water,

arising from the destruction of that portion of the starch which was utilized as a source of energy for the constructive processes. The carbon dioxid and water are waste products and are liberated at once by the process of excretion.

Thus it will be seen that there are two processes going on in a plant body. One — *photosynthesis* — is a constructive process by which the sun's energy is stored; the other — *metastasis* — is a destructive process by which the energy is liberated. The former process is going on in green leaves and only in sunlight; the latter takes place in all of the living parts of the plant, whether in sunlight or in darkness, at all times when the plant is carrying on its life processes. By the former process starch is being made; by the latter the plant manufactures a host of materials which are stored away in its body in the form of proteids, wood, fat, cellulose, or other substances.

Plants Produce an Excess of Organic Material.— In all green plants, photosynthesis is much in excess of the metastasis, and green plants are constantly manufacturing a quantity of starch and other organic products, far more than they need for their own use.

The materials thus produced serve not only as a reserve for their own future use but also for most other forms of activity on the earth. All fuel which is used by our numerous engines, whether wood, coal, oil, or gas, can be traced back to plant life, and represents, therefore, the sun's energy stored by photosynthesis. The food of all animals also comes from plants.

THE LIFE OF AN ANIMAL

Stored Energy Utilized by Animals.—The only source of energy available for animals and colorless plants is that stored up by green plants, and rendered available when liberated by the destruction of the compounds that hold it. The general result of animal life is a destructive one, with its resulting liberation of potential energy. Animal protoplasm is, however, able to carry on some constructive work. It can make fats

out of starches, can convert one proteid into another, and can make new living protoplasm if fed with lifeless proteids; all of these are constructive processes. Whatever energy is needed for this work must be obtained by breaking down part of the food, so that the result is a reduction of the total amount of organic materials. In their constructive work, animals are not only unable to make starches and sugars, but they are unable to make proteids. Since they require these as materials out of which to manufacture muscles, nerves, glands, etc., it follows that they are dependent upon plants, not only for starches but also for proteids, which the plants manufacture and which the animals utilize.

From this outline of the transformation of energy it is evident that living organisms, both animals and plants, are in a strict sense machines. That living beings possess special powers shown by no other kind of mechanism, and therefore belong in a category by themselves, is very evident; but so far as concerns the problem of energy they are machines. Vital energy is only the energy of sunlight transformed into various types within the mechanism of the living machine. Since coal is simply an accumulation of the remains of plant life of past ages, we now see the source of its energy. It contains the stored sunlight of the past.

CHAPTER XVI

THE MECHANICS OF THE LIVING MACHINE

In the general comparison of the living body with a machine, a number of significant conclusions are reached when we carry this comparison out in detail.

Are the Income and Outgo Equivalent?—Can all of the energy shown by the living organism be accounted for by the energy furnished by the food, and, conversely, can all of the energy furnished in the food be accounted for in the form of energy exhibited in the living organism?

If the law of the conservation of energy is correct, the answers to these questions must be in the affirmative. To get an experimental answer is not easy, but it has been done, as follows: A large box has been constructed in which is placed an animal, or sometimes a human being, and then the box is sealed. By means of ingenious apparatus the person inside of the box is furnished with the necessary air to carry on his respiration, and is given plenty of food and water; he remains in this box for a varying length of time. The apparatus is designed, not only to determine the exact amount of water and food that the individual consumes, but also the amount of oxygen he takes from the air, the carbon dioxid he breathes into the air, together with all the moisture that is eliminated from the body, and all other excretions. Moreover, the amount of energy furnished him in his food is measured, and the amount of heat liberated from his body is determined with accuracy, as well as the amount of work that he does.

If the doctrine of conservation of energy holds concerning the animal body, as it does concerning other machines, it ought to be found by such an experiment that the amount of energy exhibited by the individual is identical with that furnished in his food, and that the amount of excretions is exactly equiv-

alent to the amount of food consumed in his body during this given time. The difficulties of carrying on such an experiment have been great, but they have been surmounted satisfactorily, and the results are always the same. There is an exact equivalence between the income and the outgo of a living animal, both as to force and matter. The amount of excretion from the individual is exactly equal to the amount of food consumed; and the amount of energy developed is the exact equivalent of the energy contained in the food that he uses during the same experiment. The general conclusion is that the income and the outgo of an animal balance, and that the living machine, like other machines, simply transforms one form of energy into another without creating or destroying it. In this statement no account is made of the energy of the action of the nervous system, which does not show itself in such experiments, the probable reason being that the recording apparatus is too coarse to show an amount of energy so slight as that exhibited by the nervous system.

DETAILS OF THE ACTION OF THE MACHINE

In the running of an ordinary machine, like a steam engine, we understand fairly well the details of its action. We can understand how the forces of chemical affinity break up the chemical compounds in coal; how the heat thus liberated vaporizes the water; how the water under pressure acts on the piston in the cylinder, and how this produces the revolution of the flywheel. It is true that we do not understand the forces of chemical affinity by which coal burns, but, apart from this, there is nothing mysterious in the fact that the engine converts the stored-up energy contained in the coal into the motion of the flywheel. Is a similar intelligible explanation possible of the activities that go on in the living organism? In other words, do chemical and physical forces suffice to explain the activity of the living machine, just as they do the activity of the non-living machine?

To follow out this question in detail would take more space than could be devoted to it here. A few of the more important functions of life may be considered, and will serve to show how modern biological science endeavors to explain life phenomena in terms of chemical and physical forces. In this discussion we shall confine our attention wholly to the life of animals. The life of plants is far simpler than that of animals, and if it can be shown that the animal organism works in a mechanical fashion, we may safely assume that the same principle will hold for the vegetable kingdom. In following out this thought we will consider in succession several of the important functions of animal life.

Digestion.—Digestion is simply a chemical change in the nature of the food, and involves nothing mysterious, nor any special forces. The foods when taken into the body are mostly insoluble. In order to pass through the walls of the intestine, they must first be dissolved in the liquids of the digestive tract, and before they are dissolved they must be changed into a soluble condition. The changes which make them soluble are not peculiar to the living body, since they will take place equally well in a chemist's laboratory. One of the most important steps in digestion is the change of starch into sugar; and starch, by proper chemical methods, can be changed into sugar just as readily in the test tube of a laboratory as in the digestive organs of an animal. The digestion of starch has nothing mysterious in it, and is only an instance of the application of the well-known chemical forces. The same thing is true of all the other changes in the food which we call digestion. They are all chemical changes, resulting from the laws of chemical affinity. The only feature concerning the process that is not intelligible in terms of chemical law is the nature of the digestive juices. The digestive juices contain substances that have the power to bring about chemical changes. If we mix starch and water together they will not combine to make sugar, but will remain a mixture of starch and water. If, however, to this mixture

we add a little of the secretion of the pancreas, the starch and the water will chemically combine to produce sugar, a new compound. The pancreas produces a substance which is called **amylopsin,** which has the power of causing a chemical union of the starch with the water. This substance we call an **enzyme.** It is not alive nor does it need any living environment for its action. If we separate a little of it from the pancreatic juice and put it in a test tube with water and starch, it will cause the union of the water and the starch exactly as it does in the digestive tract. Now we do not know exactly the nature of this enzyme, nor just how it brings this union about; therefore the vital process of digestion is not entirely understood at present. We do know, however, that digestion itself is only a chemical change, and that the same chemical union of the starch with the water can be brought about without the presence of this enzyme. The fact that we do not exactly understand how the pancreatic juice acts in this case is no stranger than the fact that we do not understand exactly how a spark causes a bit of gunpowder to explode. We do not doubt that the explosion of the powder is the result of chemical and physical forces, and there is no more reason to doubt that the combination of the starch with the water, under the influence of amylopsin, is also the result of chemical and physical forces.

The same principle holds in regard to the digestion of all other foods in the digestive tract of animals. Each of the digestive juices contains special enzymes, each food is acted upon by enzymes, and in all cases the food undergoes a chemical change. Apart from the fact that they are brought about by these enzymes, there is little or nothing to distinguish between chemical changes taking place in the body and similar changes taking place outside of the body. Digestion, in other words, is a chemical process and controlled by chemical laws.

The Absorption of Food.— The digested food passes through the intestine, being forced along by the muscular action of the intestinal wall. As it passes through the intestine it is

gradually absorbed, soaking through into the blood vessels that lie within the walls. This process of food absorption involves another set of forces, which are, at least to a considerable extent, either chemical or physical. The primary force concerned is what physicists call **osmosis** or **dialysis,** a force which has no special connection with life. If a membrane separates two liquids of different consistency (Fig. 134), a force is exerted on the liquids that causes each to pass through the membrane in an opposite direction, until the constitution of the liquids on the two sides of the membrane is the same. The force that drives these liquids through the membrane is a powerful one, since it is exerted against a high pressure. In Figure 134 a membranous bladder is attached to the lower end of a glass tube. If a solution of sugar is placed inside of this bladder and pure water outside of it, the sugar and the water will both pass through the membrane in opposite directions. Under these circumstances, however, more water passes from the outside into the bladder than passes from the bladder outward. The result is that the bladder becomes more and more filled with liquid, and enough pressure is produced in the bladder to force the water up the tube, in which it may rise to quite a height. This force is known as **osmosis,** and it is always exerted whenever two solutions of unequal concentration are separated from each other by a membrane. Some substances, like the white of an egg, are not capable of passing through a membrane, and we refer to them by the term **colloidal** or **non-dialyzable.** Other substances, like salt and sugar, will readily pass through membranes, and we speak of them as **crystalline** or **dialyzable.**

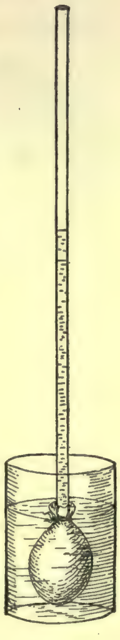

FIG. 134. — A DIAGRAM ILLUSTRATING THE FORCE OF OSMOSIS

Osmosis is the fundamental force concerned in the absorption

of the food from the alimentary canal. Undigested foods are not, as a rule, capable of osmosis. Digestion changes them into a condition in which they are soluble and capable of osmosis. After complete digestion the foods in the alimentary canal have been converted into a dialyzable liquid. Moreover, the structure of the intestine is such as to make osmosis a natural process. This can be understood from Figure 135, which illustrates a diagrammatic cross section of the intestinal wall. In such a figure the food occupies the space, *in*. The walls of the intestine are thrown into little papillæ called **villi**, each of which is covered by a membrane, *m;* on the other side of this membrane, at *bv*, there are blood vessels containing the blood, which is a liquid of very different nature from the intestinal contents. Thus it is seen that we have a membrane separating two liquids of different consistency, the blood on the one side and the digestive food on the other. Under these circumstances, the force of osmosis will develop and the material in the solution will begin at once to pass through the membrane from one side to the other. Thus the primary factor in the absorption of food from the intestines is that of osmosis.

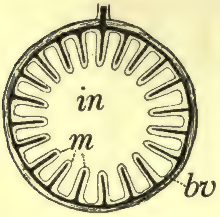

FIG. 135. — DIAGRAM SHOWING THE RELATION OF PARTS IN THE INTESTINE FOR THE ABSORPTION OF FOOD

bv, the blood vessels in the intestinal wall;
in, the intestinal cavity occupied by the digested food;
m, the membrane of the epithelial cell through which the food dialyzes into the blood vessels.

The physical force of osmosis is not, however, the only factor concerned in the absorption of food. If it were, there would be an equivalent passage of liquid from the blood into the intestine, as well as from the intestine into the blood. Such an equivalent passage from the intestine does not seem to take place, proving that the forces concerned in the absorption of food are not confined to the process of osmosis. Moreover, a careful study of the absorptive process shows that it is much more

complex than has been considered. As the food is being passed through the intestinal walls it is changed further in its chemical nature, and by the time it has reached the blood it is in a different chemical state from that in which it left the intestines.

While, therefore, osmosis is the fundamental factor concerned in the absorption of food, we are obliged to admit that it is not the only factor concerned, and that there are some phases of the food absorption that we do not yet understand. At the present time we may speak of this unknown factor as the *vital factor* of food absorption. By this term "vital factor" we simply mean the undiscovered forces concerned. No biologist doubts that the further study of the digestive process will disclose the nature of these vital forces, just as a previous study has explained the early phases of food absorption. In other words, the general belief of biologists to-day is that here the term "vital" is only a means of concealing our ignorance of facts which are yet to be discovered. We have no reason for believing that there are any peculiar forces concerned in the absorption of food. Modern biology thus explains the absorption of food by the application of the same chemical and physical forces that are found elsewhere in nature.

Circulation.—The next function in animal life is the circulation of the blood, which carries the absorbed food to the various parts of the body where it is needed. The mechanism of the circulatory system is very simple and is based upon mechanical principles. The circulating blood is contained in a series of tubes, the blood vessels, extending to every part of the body. At the center of this series of vessels there is a pump, the heart, which keeps the blood moving. The heart is like a pump, with valves opening in one direction only. Its structure is such that the expansion and contraction of its walls will open and close the valves, and cause the blood to flow in one direction. By examination of Figure 136, which represents diagrammatically the structure of the human heart,

it will readily be seen how the valves work to prevent the backward passage of the blood, and to force it onward when the walls of the heart contract. The blood forced from the heart is received in elastic blood vessels, the arteries, which branch and grow smaller as they pass from the heart, and finally break up into extremely minute and even microscopic vessels. After

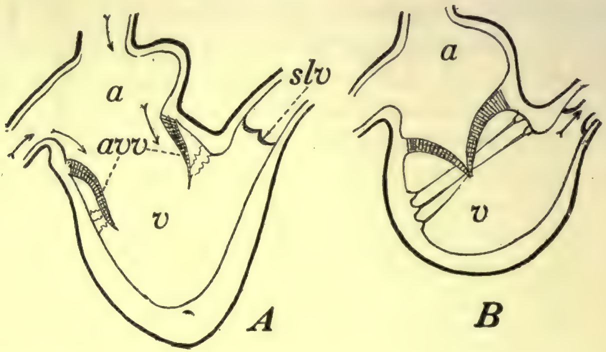

Fig. 136.—Diagram of one side of the heart, showing the mechanism of the valves

A, in the state of relaxation; *B*, at the time of contraction. In *A* the open valves admit the flow of blood from the veins into the ventricles. In *B* the valve connecting with the auricle is closed and the contraction of the heart forces the blood up through the semilunar valve, as is shown by the arrows. Upon relaxation of the ventricle, the semilunar valve closes, and prevents the flow of the blood back into the ventricle, while the auriculo-ventricular valve opens and allows blood to enter from the vein.

a, auricle; *slv*, semilunar valve;
avv, auriculo-ventricular valve; *v*, ventricle.

passing these capillaries, the vessels are again united into larger tubes which, by combining with each other, form the large veins that flow back to the heart. The whole action of this system is mechanical; and we can arrange a series of elastic rubber tubes with a central beating force-pump, in a manner to imitate the chief functions of the circulation. Into the details of this matter we need not go; for our purpose it is sufficient to understand that the circulation of the blood is a mechanical phenomenon which can easily be imitated by

machinery devised on the same general structure as the heart and blood vessels.

It is evident, however, that one phase in the circulation requires further explanation. The force that drives the blood is the contraction of the walls of the heart. Unless we explain the beating of the heart, we have not explained circulation. The explanation of this phenomenon belongs to the study of muscles, for the walls of the heart are nothing more than a chamber made up of a series of muscles. The beat of the heart is, therefore, no more mysterious than the contraction of other muscles. The contraction of the muscles, it is true, we do not yet fully understand, but we do know that muscles constitute a machine which by physical laws transforms the energy stored in the foods into motion.

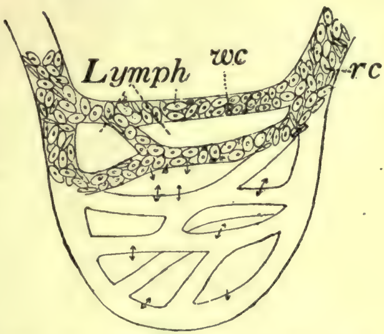

FIG. 137.—DIAGRAM OF A FEW CAPILLARIES FILLED WITH BLOOD CORPUSCLES AND SURROUNDED BY LYMPH. THE ARROWHEADS SHOW THE DIALYSES FROM THE LYMPH INTO THE TISSUES, AND FROM THE TISSUES BACK INTO THE BLOOD

wc, white corpuscles;
rc, red corpuscles.

Not only is the distribution of the blood to be explained by mechanical principles, but the method by which the blood supplies the tissues with their nourishment is fairly simple. The blood first absorbs nourishment from the alimentary canal and is then carried into the active tissues of the body — for example, to the muscles—where again it is placed in a position in which osmotic pressure will be exerted. The blood passes through the muscles in thin-walled capillaries, on the outside of which is a liquid called the lymph (Fig. 137), and thus there is a membrane

separating two liquids, *i. e.*, the capillary walls separating the blood and the lymph. Under these conditions osmosis will take place, and thus the same general force which was concerned in the passage of the materials from the intestine into the blood, will cause the passage of the same materials from the blood vessels into the lymph in the tissues. This lymph lies in direct contact with the living cells, and these living cells can now take from the lymph the food material that they need. This latter function, by which the living cells take the material that they need, is not explained by any known force, so we speak of it as due to what we still call vital force.

Respiration.—The absorption of oxygen by the blood in the lungs of a frog or the gills (*branchiæ*) of a fish, and the elimination of the carbon dioxid, are also processes which are explainable by simple chemical laws. The blood contains certain substances which have a chemical affinity for oxygen, and others which have a chemical affinity for carbon dioxid. The red coloring matter, hæmoglobin, has a chemical affinity for oxygen, and will absorb the gas whenever it is in contact with it, provided the pressure of the oxygen is sufficient. But this union is a peculiar one. If the atmosphere contains oxygen under high pressure, the hæmoglobin will unite with the oxygen, but if the oxygen pressure is low the hæmoglobin will let go of the oxygen. As a result, whenever blood passes through the lungs, where there is a large quantity of air and where oxygen is under high pressure, the hæmoglobin combines with oxygen; Fig. 138. The blood is then carried around the body, and when it reaches the active tissues, like the muscles,

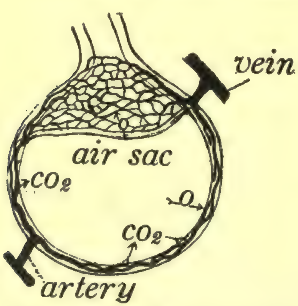

FIG. 138.—AN AIR SAC OF THE LUNGS

Showing the blood vessels distributed in the wall in position to absorb oxygen from the cavity of the sac and excrete carbon dioxid into it.

the glands, or the brain, it finds a condition where there is practically no free oxygen. Here, since the oxygen pressure becomes reduced, the hæmoglobin at once lets go its hold upon the oxygen which it has seized in the lungs. The oxygen then passes off rapidly into the tissues and the blood is carried back again to the lungs to get a fresh supply. There is a similar relation between carbon dioxid and the blood; when the pressure of carbon dioxid is high the blood will absorb it, and when the pressure is low, the blood will let go its hold upon the carbon dioxid it has absorbed. In the active tissues and cells, carbon dioxid is present in considerable quantity, as the result of the activity of the tissues. When the blood flows through these tissues, it therefore absorbs carbon dioxid, and then goes back to the lungs loaded with this gas. In the lungs, however, it comes in contact with the air, in which the carbon dioxid is present in very small quantities only. Under these circumstances the blood can no longer hold the carbon dioxid. This gas passes into the lungs and is exhaled in the next breath. These two processes are purely chemical; they will take place just as well in a laboratory as in the lungs, and are quite independent of any vital factors.

Up to this point in the study of the activity of the living body, there is no special difficulty in reaching the following conclusions: (1) So far as relates to the general problem of the transformation of energy, the body neither creates nor destroys energy, but simply transforms one kind into another. (2) So far as concerns the functions now considered, the laws of chemistry and physics furnish for them an adequate explanation.

It is necessary, however, to question further a function of life in which the mechanical relation is less obvious. The nervous system controls all the operations of the body as an engineer controls an engine. Is it possible that this phase of living activity can be included within the conception of the body as a living machine?

The Nervous Functions.— The primary question is whether there is any correlation between nervous force and other types of energy. For this purpose it will be convenient to separate the phenomena of simple nervous transmission from those that we speak of as mental phenomena. The former are simpler and offer the greater hope of solution.

Nerve impulse.—If we are to find any correlation between nervous force and physical energy, it must be done by finding some way of measuring nervous energy and comparing it with physical energy. There has been devised as yet no satisfactory way of measuring the nervous impulse directly. In the experiment of keeping an individual in a large box where all of the energy exhibited by his body can be carefully and accurately measured, the attempt has been made to get some indication of the energy involved in nervous phenomena. But the results have been quite negative. When in these boxes an individual simply arises from his chair, the measuring device of the apparatus is accurate enough to show distinct indication of the expenditure of energy in this very simple motion. But when this person is allowed to remain seated, not performing any bodily action, but working hard with his brain, as for example in writing a difficult examination, there seems to be exhibited no extra energy, so far as can be determined by the measurement recorded with this apparatus. In spite of all attempts that have been made, it has hitherto been impossible to get any indication that the use of the nervous system involves the expenditure of energy. This is probably due to the fact that the amount of energy thus involved is altogether too small to be recorded in the coarse apparatus which has been devised for use in these experiments.

That there is some correlation between nervous force and physical energy is fairly well proved by experiments along various lines. The impulse that passes along nerves may be excited by a variety of forms of ordinary energy. Any mechanical shock, a little heat, or an electrical shock will develop a

nervous impulse. Now, if forms of physical energy applied to a nerve are capable of giving rise to a nerve stimulus, the inference is certainly a legitimate one that the nerve is simply a bit of machinery which converts one kind of energy into another, *i. e.*, converts physical energy into nervous energy. If this be the case, of course it is necessary for us to regard nervous force as one of the correlated forms of energy.

Other facts point in the same direction. Not only can the nerve stimulus be developed by an electric shock, but the strength of the stimulus is, within certain limits, proportional to the strength of the shock producing it. Conversely, we also find that a nerve stimulus produces electrical energy. In an ordinary nerve, even when it is not active, there are slight electric currents that can be detected by very delicate apparatus. If the nerve is stimulated, these electric currents are immediately affected in such a way that they may be increased or decreased in intensity. These variations in intensity are sufficient to be visible by delicate apparatus, and by using a galvanometer we can actually measure the passage of an impulse passing along a nerve like a wave, and can approximately determine the shape of the wave.

Since the nervous impulse can be started by some other form of energy, and since in turn it can modify ordinary forms of energy, we cannot avoid the conclusion that the nervous impulse is a special form of energy developed within the nerves. It is possibly a form of wave motion, peculiar to the nerve substance, but correlated with and developed by other types of energy. This of course would make the nerve fiber a simple bit of machinery.

If this conclusion is correct, it will follow that whenever a nerve impulse passes over a nerve a certain portion of the food supply in the nerve must be broken to pieces to liberate energy, and this would also be accompanied by the elimination of carbon dioxid and heat. But although careful experiments have been made, it is as yet impossible to detect any rise in

temperature when a nerve impulse passes over a nerve. This is not, however, an objection to the general theory, since the nerve is such a small machine that it would be doubtful whether our tests are delicate enough to recognize any rise in temperature even if such a rise occurred. The total energy of the nervous impulse is too small to be detected by our rough instruments for measuring heat.

All evidence goes to show that the nervous impulse is a form of motion, and hence is correlated with other forms of physical energy. The nerve is a very delicate machine and its total amount of energy is very small. A tiny watch is more delicate than a water-wheel, and its actions are more closely dependent upon the accuracy of its adjustment. The water-wheel may be made very coarsely and still be useful, while the watch must be fashioned with extreme care and nicety. Yet the water-wheel transforms vastly more energy than the watch; it may drive the machinery of the whole factory, while the watch can no more than move itself. But who can doubt that the watch as well as the water-wheel is governed by the law of the correlation of forces? So the nerve machine of the living body is delicately adjusted, easily put out of order, and its actions involve only a small amount of energy; but it is probably just as truly subject to the law of the conservation of energy as are the more massive muscles.

Sensations.—Up to a certain point, sensations can also be related to the general problem of the conservation of energy. The frog has a piece of apparatus, which we call the ear, capable of being affected by the vibrating waves of the air. It is made of parts so delicately adjusted that the air waves set them in motion, and this motion starts a nervous stimulus which travels along the auditory nerve to the brain. Whenever air waves strike the frog's ear, they will excite in his auditory nerve impulses which will travel from the ear to the brain. The ear is simply a delicately poised apparatus, so adjusted that when it is stimulated by vibrating air it is discharged like a bit of

gunpowder, and a nervous impulse is produced. In all of this we are plainly dealing with nothing more than the transformation of one type of energy into another. In the same way the optic nerve has at its end, in the eye, a bit of mechanism that is easily excited by the light waves, and when such waves strike the eye there will be started in the optic nerve a series of impulses which pass towards the brain. Thus each sensory nerve has at its end a bit of machinery designed for transforming certain kinds of external force into nervous impulses.

The second phase of the sensation is, on the other hand, not explainable by any mechanical principle. When the impulse started in the ear reaches the brain, it is converted into what we call a **sensation,** *i. e.*, a *consciousness*, a *perception*, a *distinct feeling*. In our attempt to trace external forces we can follow the stimulus to the brain, but there we must stop. We have no idea how a nervous impulse is converted into sensation. By no means of thinking can we conceive of the correlation of the sensation itself with any form of physical energy. It is true that the mental sensation is excited by the nervous impulse, and true also that in the development of the individual the mental powers develop parallel with the growth of the nerves and brain. Moreover, certain visible changes occur in the brain cells when they are excited into mental activity. All of these facts point to a close association between the mental side of sensation and the physical structure of the machine. But they do not prove any correlation between them. The unlikeness between the mental and physical phenomena is so absolute that we must hesitate about drawing any connection between them. It is impossible to conceive of the mental side of sensation as a form of wave motion.

Mental functions.—If we go farther and try to consider the other phenomena associated with the nervous system—the more distinctive *mental* processes—we have absolutely no ground for comparison. We cannot imagine thought measured by units; and until we conceive of some such measurement we can get

no meaning from any attempt to find correlation between the true mental processes and physical energy.

Reproduction.— The process of reproduction would seem to be one which cannot possibly be explained as the result of chemical and physical forces. Nowhere else in nature do we find this property, and in this respect living organisms cannot be compared to any other machine. Nevertheless, in its simplest form reproduction also permits a partial explanation. When a unicellular organism, like the *Amœba* (Fig. 19), feeds and grows, it increases in size. The increase in size is due to the transformation of the chemical material of its food into a material like that of the animal, and as these new materials accumulate, the bulk of the animal becomes greater. As the animal increases in bulk, it needs a larger supply of oxygen to keep up its life processes, since all life processes require the expenditure of oxygen, and the amount of oxygen needed is dependent on the bulk of the animal that is to be supplied. Now it is a principle of mathematics that the bulk of a solid object increases as the cube of its dimensions, whereas its surface increases only as its square. Since this *Amœba* is obliged to absorb all of its oxygen through the surface of its body, it follows that the surface adapted for absorbing of oxygen increases only as the square of its diameter, while its need for oxygen increases as the cube. It is evident from this that in time the surface will no longer be sufficient to absorb enough oxygen for its increasing size. When this time comes the animal must either stop growing or devise some way of increasing its absorptive surface. What happens is that the bit of living jelly simply breaks in two. The result is that once more the absorbing surface is large enough to accommodate a larger bulk, and the animal again begins to grow. This explanation of reproduction shows how the process may have been due to overgrowth. Since all kinds of reproduction are forms of division, it follows that if we can explain the simplest division upon the basis of physical and chemical forces, we have at

least reached an intelligible understanding of the process. The more complicated phases of reproduction are, of course, not explained by this simple process, not even the division of a cell which we have seen to be very complicated; but if we can explain this strange phenomenon even in its simplest form, we have done much toward explaining the functions of reproduction in accordance with the principle of chemical and physical forces.

VITAL FORCE OR VITALITY

With all of the explanation given, we cannot believe that we have reached a solution of life. There is clearly something lacking, for we still have to ask the question why it is that all of these chemical and physical forces play together in such harmony within the living organism. Nowhere in nature can the physical forces automatically carry on such functions *except in living organisms.* It is quite possible to compare the animal body to a locomotive at rest. But a locomotive at rest, even if its boilers are filled with steam under high pressure, will never exhibit any activity without an engineer to control the forces that are contained in the machine. The living organism has no outside engineer. What is there in the living organism that corresponds to the engineer starting and directing the machinery? To this question we have no answer. Some biologists claim that there is no more need of an engineer for a living organism than for a clock, these scientists assuming that the complexity of the machine gives it automatic activity. Others would believe that in a living being there is something that is absent in other machines, to which they would give the distinct name of *vitality.* There are certain functions of this machine, like *sensation, thought,* etc., that do not seem to be explainable by chemical and physical laws, and one class of biologists would group these functions together under the general term of vitality. Others would claim that vitality has no real meaning, but is only a *name* given to a combination of functions possessed by certain machines. The question

whether there is anything like vital force has not yet been solved, and it is by no means certain that it ever will be. If it were possible for scientists to manufacture a cell exhibiting the properties of life, the great problem of biology would be settled. This has never been done, and we must leave the question of the meaning of *vitality* without an answer. It cannot be insisted upon too strongly that, while we may compare the living organism with a machine, it is unlike any other machine. The living machine consists of a number of small independent units called cells, each one of which has its own independent power of growth and reproduction. The whole combination, too, has functions possessed by no other machine.

Complex and Simple Living Machines.—An animal as high in the scale as the frog is evidently an extremely complicated machine. Not only is it made up of a large number of parts, each with a different function, but each of these parts is made up of a number of tissues, each having a different relation to the organ in general; and furthermore, each of these tissues is made up of hundreds, thousands, and perhaps millions of living units, called cells. It seems plausible to think that, if we could get rid of the complexity seen in the frog, we might approach nearer to primitive life. In other words, if we can get at the simplest unit of life we might be able to understand many mysterious phenomena, since we should thus approach life in its simplest form. For this purpose biologists have turned especial attention to the life of the individual cell, since this is the simplest known unit manifesting life. It is clear, however, from the study of cells in Chapter II, that the mysteries of life phenomena are not solved by reducing them to the operations going on inside of the single cell. Although some cells are simpler than the one shown in Figure 9, still it represents practically the simplest form of machinery with which we are acquainted that is capable of carrying on the functions of life. But such a cell itself is a complex machine, and if we study in

it the processes of life, it becomes evident that the functions of this single machine are as mysterious, although not so complex, as are the functions of the whole body of the frog. In other words, getting rid of the complex machinery of such a highly built organism as the frog does not help us at all towards the solution of the problems of biology; for it is no easier to understand the processes of life going on in the single cell than it is to understand the processes of life going on in the multicellular animal. While the study of single cells and their functions has enabled us to understand the processes of life in many respects much better than before, it has not solved the problem of what life is, nor made it any easier to get rid of the idea that living organisms show certain powers not possessed by machines, — powers so mysterious that we must acknowledge our inability to explain them, and must, for the present at least, include them under the general term of vitality.

The recognition that the cell is such a complex mechanism has recently led to the attempt to analyze it into smaller and simpler units. Whether any success will follow this attempt it is too early to predict.

For these reasons it is useful still to retain the term "vital force"; not meaning by this to imply that there is any special force in living things, uncorrelated to forces of nature, but simply indicating our present lack of knowledge. By vitality we refer to the guiding principles which regulate the play of chemical and physical forces in this living machine, and which determine the processes of reproduction, which lie at the foundation of that side of living organisms and their functions which we call mental. We certainly have not yet explained all the factors connected with life processes, and we can therefore most satisfactorily comprehend them under the term "vitality." With this understanding, it is perfectly legitimate to retain the term "vital force" for those phases of life processes which are not included in any mechanical conception of life.

SUMMARY

1. All physical energy exerted by the living organism is distinctly correlated with other forms of energy, the energy of plants coming from sunlight, and that of animals coming from the energy stored by plants in their foods. To this extent, therefore, a living organism is a machine. 2. Nearly all life functions are explainable by chemical and physical laws. This is certainly true of such functions as *digestion*, *assimilation*, *circulation*, *excretion*, *respiration*, etc. 3. Some of the functions of the living animal are not yet explained by chemical or physical forces. This is true of the *absorption* of the food from the intestines, and the power which the living cells have of taking from the lymph the particular form of food that they need. We may gather these factors for the present under the term "vital forces" of the living organism. After we have learned thoroughly to understand them and their method of action, we may find these processes are also to be included under the general laws of physics and chemistry. There is really no good reason for questioning that the living organism is a mechanism, simply because there are some functions which are at present unintelligible. 4. In the *mental* power of the living organism appear functions which are not found in any machine. The functions of *mind*, *sensation*, and *thought* are so absolutely unique, and so different from any other type of energy, that no one has ever conceived the possibility of correlating them with physical energy. 5. Only the living machine has the power of reproducing itself. It is true that some forms of the process of *reproduction* may be explained simply as a result of growth, and growth as due to the chemical forces that are at play within the living organism. But it nevertheless remains true that no other mechanism in nature has the power of dividing itself into two parts, each of which develops into an individual like the first. Taking all these things into consideration, it is evident that, so far as physical forces are concerned, the living organism is a machine, and, like other mechanisms,

transforms one type of energy into another. But the living organism possesses additional powers, some of which may be explained some day, while others, like thought and reproduction, appear to be insoluble and place the living organism in a category by itself. If the living organism is a machine, it is also more than a machine, and cannot be compared with any other mechanism in nature.

WHAT IS LIFE?

It may be instructive to ask whether we can define life. Although many attempts have been made to give the definition of life, all that can be done is to describe some of its characteristics. The primary characteristic of living things is a constant activity, and if we mean anything by the term "life," it must be the guiding force that controls these activities. Our understanding of the word "*life*" is certainly obscure; but, so far as it means anything, it refers to the engineer that controls the engine, the machinist that directs the activity of the machine, the force that guides the activities of the animals or plants. What this guiding force is we do not know. Some have called it "*vital force*," and have believed it to be a special force in nature. Others insist that there is no special force in living things, any more than there is in a clock or a watch. Whether there is any force in nature that can properly be called *vitality* is not yet settled, but it is certain that the phenomenon which we call life is manifested only in those machines which we call animals and plants, and which come from no source except that of previously existing animals and plants. We have no evidence that this force can be created in any way except from life which previously existed. The life force is capable of indefinite growth and expansion, since a fraction of life force, in the form of any single animal, may produce hundreds of thousands of offspring, each of which has the same amount of life force as the original ancestor had. But this life force, although capable of expansion and growth, has, so far as we

know, no method of origin except from previously existing life. We must look at life as a unique manifestation of force, standing by itself. This is perfectly consistent with the recognition of the fact that the animal body is a machine, acting in accordance with the principles of conservation of energy, and that a living organism simply transforms one type of energy into another. This view is also equally consistent with the suggestion that there is a special force, which we call life, directing the activity of these machines. At all events, for the present we can go no farther in the discussion of the question than this. Life is the directive agent which controls the activity of the living machine, and death means the disappearance of this controlling agent; though what is meant by its disappearance we cannot say, any more than we can tell what caused its appearance in the machine in the first place. The question of the real significance of life and death is still unanswered by science.

CHAPTER XVII

THE ORIGIN AND DEVELOPMENT OF ORGANISMS: HEREDITY AND VARIATION

THE ORIGIN OF THE LIVING MACHINE NOT EXPLAINED

Even if it were possible to explain perfectly the working of the organic machine by mechanical principles, this would not explain life. As we have noticed in Chapter I, living organisms come into existence to-day only as the result of reproduction from previously existing organisms. Granting that animals and plants have the power of reproduction, we have still to ask how these complicated machines came into existence. One of the most revolutionary eras of thought has arisen in the last fifty years as the result of the attempt of biologists to explain how the innumerable animals and plants have been brought to their present condition of existence.

Of the primal origin of life we have no knowledge, and it must be admitted we have little hope of ever gaining any. Nor have we much idea of the first living things that appeared in the world. Probably they were of the lowest type, possibly even simpler than unicellular forms. One thing seems certain: the first living things must have been endowed with the properties of growth and reproduction; for without these powers they would not have been alive. We know of nothing simpler than cells possessing these powers, and we cannot therefore conceive the beginning of life as anything simpler than a bit of reproducing protoplasm.

THE FORCES WHICH HAVE PRODUCED ORGANISMS

It has been the aim of biology to show how the endless series of complicated animals and plants, now found in the world, have been produced from the simplest forms of life.

Living organisms possess three properties, by the interaction of which the present world has been formed. These are **reproduction, heredity,** and **variability.** That these three factors are necessarily concerned is evident. Without **reproduction** there could not have been produced the successive generations which have followed each other; unless the successive generations had, by **heredity**, reproduced the characters of preceding generations, there would have been no connection between one type and another; and lastly, if the successive generations had not shown **variability,** organisms would have remained in a stationary condition, without any opportunity for change. That these forces have been *sufficient* to account for the development of the organisms inhabiting the world, *i. e.*, to explain the origin of the living machines, is not so evident. To show how the result has been brought about has been the endeavor of biological discussion for the last half-century. The property of reproduction we have already considered. The consideration of heredity and variation remains.

Heredity.—The general rule in reproduction is that the offspring grow into individuals like their parents, the repetition of the parent being spoken of under the name of **heredity.** Heredity must not be looked upon as any special force or law, but merely as a word expressive of the fact that one generation repeats itself in the next. It is evident that this process of repetition cannot be exact, since most animals have not one but two parents, and an individual that has a father and a mother cannot be exactly like both of them if they are in the slightest degree unlike. Since no two animals are exactly alike, the natural conclusion would be that the offspring would be a compromise between its two parents. Successive generations are thus not identical, but constantly show differences from their parents. Heredity means, then, that successive generations resemble their parents as closely as is compatible with the fact that the individual has two parents, and cannot be like both.

Variation.—The offspring of any animal is never exactly like either of its parents. Sometimes it is a compromise between them; sometimes, for certain reasons that we do not understand, it is quite different from either. The reasons why any peculiarity may reappear in successive generations, are probably partly due to processes connected with the reproductive functions, but they are also partly due to the effect of the environment in which the animal lives, upon the structure, the nature, and the life of the organism. Whatever be their cause, the points in which animals and plants differ from each other, or from their ancestral types, are known under the general name of **variations.**

The life of an individual which is produced by sexual reproduction may be said to begin at the moment when the sperm fuses with the egg, as shown in Figure 121. Previous to this, there were only the sex cells produced by two parents; but from this point there is a new individual resulting from the union. Variations which appear in an animal or a plant may be caused by influences acting either before or after the union of the sex cells. If the variation is caused by influences acting before this union, we speak of it as a **congenital variation** (Lat. *con* = together + *genitus* = produced). If, however, the variation is developed in the animal after the fusion of the sex cells, and thus produced by influences acting directly on the new individual, we speak of it as an **acquired variation.** Although this distinction between acquired and congenital variations may be merely a matter of a short time, nevertheless the facts show that there is a very great distinction between characteristics produced before and after this period. Variations which are produced by influences acting before the fusion of the sex cells (congenital variations) are practically certain to be handed to the subsequent generations by heredity. Variations which arise subsequently, and affect the new individual only (acquired variations), are practically certain not to be handed on to the following generations by heredity.

CONFORMITY TO TYPE

Nothing is more marvelous, and at the same time more evident, than the fact that the individuals of generation after generation resemble each other so closely. Not only in general features, such as the structure of the body, the presence of the proper number of legs, arms, etc., does the child resemble the parent, but in an infinite number of details,— in the color of the eyes, the color of the hair, and even in many obscure traits. The child may inherit from its parents the tendency to become bald-headed at a certain age, or at a certain time in life to put on a large amount of fat, etc. Through an endless series of details, the child has a tendency to repeat its parents' characteristics.

Since scientists have begun to study life phenomena, they have always puzzled over these marvelous facts, and have advanced many speculations and theories to explain the similarity of the offspring to its parents. Some of these theories have been ingenious, some have been plausible, but all have been imaginative. For the last century, particularly, this subject has been a matter of speculation; but until about 1884 none of the various speculations had sufficient plausibility to receive any general acceptance.

In 1884 there appeared a little essay by August Weismann entitled "On Heredity" which advanced a new suggestion for the explanation of heredity. In some of its phases this new theory had been antedated by the writings of Brooks in America and Galton in England. Nevertheless, it did not appear in a clear-cut form until Weismann's essay came out in 1884, and the theory has been almost universally known as Weismann's theory of heredity. From the time of its appearance, the explanation commanded wide acceptance and extended discussion. As year by year has passed, the theory has been more and more substantiated by facts, until at the present time it has practically universal acceptance. While it cannot be claimed that we have a complete explanation of heredity, it is beyond ques-

tion that our present understanding gives us an intelligent grasp of the law of conformity to type. Future experiments and discussions may modify our present ideas in many details; but it is practically certain that the fundamental law, in accordance with which successive generations tend to resemble one another, is now so well understood that it is not likely to be changed greatly by subsequent investigation. The principle underlying this conception of Weismann's is spoken of as that of the **continuity of germ plasm.** A brief résumé of the theory is as follows: —

Reproduction by Simple Division.—It is not difficult to understand that when an animal multiplies by simple division, the offspring will be similar to each other. When, for example, an *Amœba* divides, it would be almost impossible to see how the two parts should be otherwise than alike, since they are each half of the same individual. So, too, when yeast multiplies by budding, it is not difficult to understand that the buds which grow from the side of the older cell will be like the old cell. If a cell is thus capable of dividing, it would be very difficult to see how the bud could in any degree be unlike its parent, except as it may be changed by future conditions. So, too, with those multicellular animals and plants that multiply by the process of budding, the conformity to type is natural rather than marvelous. When *Hydra* (Fig. 69) produces a small bud on its side, which grows to the size of the original and then breaks away, it is not difficult to see why the bud should be like the parent, for it would be difficult to understand how it could be otherwise. So, too, when a branch of a tree is broken off, takes root, and grows into a new tree when placed in the ground, it would be difficult to understand why the new individual should be different from the parent tree, since it is really a part of it. In all of these cases the conformity to type is natural and presents no special puzzle, beyond the fact that animals and plants have the power of dividing and reproducing at all. Conformity to type in

animals that multiply by simple division, or by budding, explains itself.

Reproduction by Eggs or by Spores.—When we come to the reproduction of the multicellular animals and plants by eggs and spores, the problem, however, becomes more difficult. The egg or the spore is a single cell, and from this single cell develops the many-celled adult. When this cell divides into many cells, which become differentiated and form themselves into new individuals, why should these adults be repetitions of the parent? There can be only one answer. This single cell, whether an egg or a spore, must contain in itself, in some form or other, features representing the whole of the animal from which it came. We may place two eggs in an artificial incubator and hatch them by artificial heat under identical conditions; one of them becomes a duck and the other a chick. It is absolutely impossible to avoid the conclusion that in one of the original eggs there were present potentially the characters which would produce the duck, and in the other the characters which would produce the chick. This of course indicates a complexity in the egg far beyond the possibility of our imagination. But we are logically forced to the conclusion that the facts are as stated. An egg or a spore undoubtedly contains potentially all of the characters of the animal into which it develops.

Germ Plasm.—For convenience in discussion it is agreed to call this substance, which is present in the egg and contains the hereditary characters, by the name of **germ plasm.** We have seen, in Chapter XII, reasons for believing that this material is chiefly, if not wholly, confined to the part of the egg that we have called the chromatin. We have also learned that the chromatin is capable of growing and dividing and has the power of self-perpetuation. Using the term "germ plasm" for this material that possesses the power of determining the development of a new individual, it follows that the germ plasm has the power of growth. In other words, this germ substance,

when properly nourished, continues to increase in bulk and may grow indefinitely, becoming more and more abundant, but not essentially changing its character. If we admit this power of the germ plasm, the problem of the conformity to type obtains a ready explanation; for some of this germ plasm is simply handed on from one generation to the next, constantly growing in bulk, but not changing its character. At any stage in the development of the race, there is present in each individual a certain amount of germ plasm, containing in itself the general race characteristics. The way that this is brought about is believed to be as follows: —

In each egg produced by an animal or a plant, and in each sperm produced by the male, there is a small quantity of this

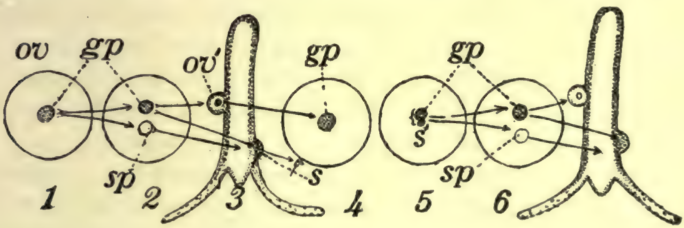

FIG. 139.— DIAGRAM TO ILLUSTRATE HEREDITY, SHOWING TWO GENERATIONS OF *HYDRA*

gp, germ plasm; *sp*, somaplasm;
ov, an ovum; *s*, sperm.

The diagram shows how the germ plasm in the egg, *ov*, divides: one part, *sp*, develops into the next generation, while the other part, the germ plasm, *gp*, becomes stored in its reproductive bodies, ov^1 and *s*. In *5*, the germ plasm from an egg is combining with the germ plasm from the sperm, s^1, in sexual fertilization.

germ plasm; Fig. 139 *gp*. It is the presence of this germ plasm that makes it possible for the egg to develop into a new individual like the parent. An early step in the development of this egg toward the adult consists in the division of this germ substance into two parts. The two are essentially alike and both contain the same characteristics; but each has a different purpose.

One of them remains exactly as it is at the start, increasing

by growth but not changing in nature. Thus this substance remains as germ plasm, *gp*. The other bit of the original germ plasm, however, soon begins to develop into a new individual, and in distinction from the other germ plasm is called **somaplasm** (Gr. *soma* = body + *plasma* = substance), *sp*. With the development of the egg the dormant power, which this somaplasm possesses, begins to show itself in an active form. As a result there appears a new individual; the second generation (Fig. 139, *3*) arises from this somaplasm. The second generation, in other words, unfolds the characters which lie dormant in the bit of germ plasm from which it was derived. As this individual develops, the other part of the original egg, which remains as modified germ plasm, finds lodgment within the body of the new individual, and thus, when the somaplasm has developed into an adult, that adult contains, stored away somewhere in its body, a bit of this dormant germ plasm of the original egg. Since this germ plasm has not changed its nature, but has only increased in amount, its nature is of course exactly the same as that of the parent germ plasm.

When later the second generation produces eggs, some of this germ plasm, which has been stored away in the body of the second generation, passes into each of the eggs; Fig. 139, *4*. If we admit that the germ plasm has certain dormant qualities, capable of developing into an adult, it will of course follow that all of the individuals produced from bits of this germ plasm will be alike. It is thus inevitable that the third generation should be exactly like the second, since both the third and the second generations have developed from two different parts of the same germ plasm. As long as the process continues, it is evident that successive generations will be alike. Part of the germ plasm at each reproduction is handed on unchanged to the next generation; it is retained by that generation through its life, and then handed on again to the next generation. Successive generations thus carry a *continuous germ plasm*. The race is the result of the continuous germ plasm;

the individual is simply the unfolding of a bit of it, the somaplasm, which is set aside to develop into an individual for the purpose of carrying for future generations the germ plasm which is to continue the race. Heredity is thus due to *the continuity of the germ plasm from generation to generation.*

It is seen that, in accordance with this theory, heredity is simply a name given to a process of handing on from age to age a bit of marvelous material, the germ plasm, small bits of which have the property of developing into individuals. As long as this germ plasm is handed on unchanged, it will produce a succession of generations identical with each other, and there will be a conformity of type. It will be seen thus that the child does not actually inherit anything from its parents; the child and parent are alike because both develop characters that are present in the continuous germ plasm.

Variations in Germ Plasm are Inherited.— It is evident that any modification of the germ plasm must permanently affect the race. If at any period the germ plasm should be changed so as to produce in it a new character, the new character will inevitably appear, not only in the next generation, but in the following generations. Characters which appear in the germ plasm at once become, therefore, *race characters,* handed on with certainty, unless something subsequently causes their disappearance from the germ plasm.

Variation in the Individual not Inherited.—It is equally evident that any variation occurring in the body, but not in the germ plasm, will have a very different effect upon the race. The individual is only a trustee of the germ plasm which is stored away somewhere in his body. Among animals, the germ substance is largely stored away in the ovaries and sperm glands; among plants it may be more distributed, but here also it is probably located in certain parts of the plant. If we admit that the individual has nothing to do with this germ substance except handing it on to the subsequent generations, it is evident that no special change which affects the individual

himself will be transmitted to the subsequent generations. If an individual should sustain the loss of an arm, it would affect his own life, but would have no influence upon the germ substance which he has received from the egg, and which he is simply holding in trust for the next generation: his offspring will not be one-armed. So with any peculiarity developed during life, as the result of life habits or as the direct result of environment. Characters which are impressed simply upon the individual himself will have no opportunity of being transmitted to subsequent generations.

Congenital and Acquired Characters.—Thus it will be seen that variations are of two distinct types: (1) variations which appear in the germ plasm and which therefore affect subsequent generations; (2) variations which appear in the body of the individual and which are not in the germ plasm, and hence cannot affect subsequent generations. These two types of variations have been recognized for a long time, but they were never sharply distinguished until Weismann's conception of heredity brought them out in such clear contrast. Characters which result from modification of the germ plasm, and hence are inevitably transmitted by heredity, to-day are commonly called **congenital characters.** Congenital variations are fixed in the germ plasm and are therefore inevitably transmitted by the process of heredity. On the other hand, characters which are developed as the direct result of the environment, such as loss of limbs, or changes resulting from food habits, climate, etc., are commonly known by the name of **acquired characters.** The term is not a good one, for all characters are acquired at some time; but this name has been used in the discussion of the last quarter of a century, for such variations. From what has just been stated, it is evident that acquired characters, if they do not become a part of germ substance, will not be repeated in subsequent generations. Acquired characters, therefore, which an individual animal or plant develops as the result of the conditions of the environment in

which he lives, would affect his body during life, but would not be expected to affect his progeny; and acquired characters should not be transmitted by heredity. This conclusion, quite at variance with the beliefs of twenty-five years ago, has been subjected to long and exhaustive study, as a result of which the belief in the inheritance of acquired characters has gradually disappeared. The conclusion has been vigorously disputed, and, since the advancement of Weismann's theory of heredity, the most active search has been made for proof or disproof of the idea that acquired characters can be inherited. While many apparent instances of such inheritance are easily found, they all prove illusive when carefully studied, and biologists have practically agreed that there is no good evidence that acquired characters can be transmitted to subsequent generations. While the possibility of the inheritance of acquired characters cannot yet be positively denied, it is quite generally believed to-day that it does not occur. This conclusion has far-reaching results, for it entirely changes our conception of the relation of parent to offspring.

Heredity and the Union of Sex Cells.—We are in a position now to appreciate a little more fully the significance of the factor of the union of sex cells in sexual reproduction. Thus far heredity has been spoken of as associated with eggs only. A succession of similar types in successive generations can be explained as due to a division and transmission of a continuous germ plasm. But the result of such a process would seem to produce a series of like individuals, without any variation in successive generations. Successive generations are, however, not alike. Indeed, the development of animals and plants is dependent upon the fact that successive generations show more or less divergence from the original type. It is here that we see one reason for sexual reproduction.

In Chapter XII we have noticed that the really significant feature of the union of the egg and the sperm lies in the fact that each of these reproductive cells throws away part of its

chromatin in order to make room for a similar amount brought to it by the other of the two uniting sex cells. If, as we have seen reason for believing, the chromatin contains the germ plasm, this process has a most natural interpretation. The maturation of the egg and the union of sex cells bring about a new individual in which the germ plasm is a mixture from two individuals (*amphimixis*) (Gr. *amphi* = together + *mixis* = a mixing). The result is that the germ plasm of the subsequent generations will be different from that which was present in either of the parents of the last generation, since it will be a mixture of the two, and, if the parents are in any degree unlike, the mixture of their germ plasms will not be exactly like that of either. It would be impossible for any such complex things as two bits of chromatin to be mixed twice without producing differences in the mixtures. In other words, the following generation will show variations from the last. Since, however, this mixed germ plasm will be handed on to form the germ plasm of the next, and all following generations, it will follow that the variations which thus appear will be handed on indefinitely by the process of heredity, and such new characters as appear from the mixture of two germ plasms will remain *fixed in the race*. With the next reproductive generation this mixed germ plasm will again be combined with another mixture from another individual, and still further variations will appear. Successive generations will thus tend constantly to be more or less unlike their parents. Sex union of eggs and sperms, therefore, appears to be a device to bring about variation and divergence from type.

If this conclusion is correct, we should expect those organisms which multiply by sex union to show a greater amount of variation than those which multiply by the asexual process of simple division; and this appears to be a fact. If a horticulturist wishes to *preserve unchanged* a type of plant which he has found, he contrives to multiply the plant by the asexual method of budding, grafting, or cuttings. As long as this

method is continued the plants remain essentially constant. If, however, he wishes to obtain new types, he adopts the method of planting the seeds. Seeds, as we have seen, come from the sex process of reproduction, and the offspring which come from seeds show a far greater tendency to variability than those which come from buds by the asexual process. It is the general conclusion from observation that variations are more common among organisms multiplying by the sexual process. With this understanding, one purpose and function of the union of the sex cells becomes intelligible.

DIVERGENCE FROM TYPE

The term "divergence from type" is the exact opposite of the term "conformity to type." It is no less evident that animals and plants tend to diverge from the race type than it is that they conform to type. The reconciliation of these two contradictory facts is that though, in general, successive generations conform to the type of the race, the individuals show more or less variation from each other, and, moreover, the whole race is slowly changing, so that the type itself in time undergoes modifications.

Individual Variations.—An infinite number of slight differences are found between individuals of the same species. This fact is clear to everyone who is at all familiar with animals. In the human race, it is well recognized that no two individuals are exactly alike, and the same thing is equally true among all species of animals and plants. The different individuals of the same species differ in size, color, habits, and in an infinite number of minor points, like the length of legs, the length of hair, the size and shape of leaves, flowers, etc. Indeed, there is no part of an animal or plant that does not show more or less of such variation. It is so evident that it needs no further discussion. While the different individuals conform to the type of their species in general character, in numerous details they differ from each other in almost endless fashion.

Race Variations.—In addition to individual variations, the whole species may show a tendency to diverge from its original form. Races are either slowly or rapidly changing from their previous condition, so that if the members of any race living to-day are carefully compared with those living in a previous period of the world's history, it will be found that the whole race has undergone a general change which has affected all members. Such race variation commonly occurs by what is known as **divergence**. By this is meant that the descendants of one type have, by this race variation, diverged in several directions, more or less different from each other. This is explained by the assumption that the descendants from any animal remain neither exactly like their ancestors nor like each other, and that different lines of descent depart from the original type in different directions. Examples of this are numerous, but for illustrative purposes two well-known instances of such divergence will be briefly mentioned.

Breeds of pigeons.—For some centuries, breeders of pigeons have been very much interested in improving different strains of these birds, and pigeon fanciers have been careful to breed together individuals showing characters that appeal to their fancy. The result has been that the pigeons have undergone many profound changes from their original type. The original pigeon, from which all of our domestic pigeons came, is fairly well known to be essentially the same as the rock pigeon of India, a bird gray-blue in color, with bars on its breast and a tendency to perch on rocks, but never on trees. Historical and scientific evidence shows that all the numerous strains of pigeons with which our pigeon fanciers are familiar to-day have been derived from this bird. The tumblers, the fantails, the pouters, and hosts of others, have all been descended from this primitive ancestral form. The differences between these varieties are very numerous, including variations in color, length of bill, size, wings, tails, and many other points.

The differences between the breeds of pigeons, which have

thus been produced artificially, are greater than differences found among many of the wild birds that are regarded as belonging to distinct species. In the case of the pigeons, it is known from historical evidence that these different strains have all come from a common type by methods of breeding.

The dogs.—Another example, perhaps even better known, is that of the breeds of dogs. Dogs have been domesticated for a period almost as long as man has been civilized. At the present time the variety of dogs is very great, ranging in size from the great *Newfoundland* to the tiny *poodle*, and varying in color, type of hair, disposition, and almost every other respect. We can hardly conceive of two animals being much more unlike than the tiny lap-dog and the massive bloodhound or mastiff, and it is hardly possible to believe that these animals have all come from the same type. But the most careful study of the characters and history of the breeds of dogs has led to the unquestioned conclusion that all forms of domestic dogs with which we are familiar belong to one species of animal, and all came from the same type far back in history. Some varieties of dogs, like the dingo of Australia, belong possibly to a different species; but all of our common forms belong to one species and have been derived from the same fundamental stock. Here, as in the case of pigeons, the breeds have been the result of a long series of unconscious breeding experiments. Different families of human beings have had a liking for certain types of dogs and have kept by them such individuals as pleased their fancy. These have been bred together and their masters have selected from the pups those which most pleased them. This process has gone on, similar individuals being bred with each other over and over again, until the whole race has become slowly changed. Different types of dogs were selected for different purposes. The shepherd took a fancy to a different type of animal from that which was most desirable as a house dog. By selecting the dogs who could drive sheep, or the big dogs, or the fierce dogs, or the little dogs, etc., and breeding together those

nearest alike, there have been produced the different types which we have in our world to-day. Recognizing, however, that all of these types of dogs belong to the same species and must have come from a single common type, the strains of dog illustrate excellently well what is meant by race divergence.

Both of these examples have been chosen from domestic animals. There is no reason for doubting that the same facts may occur in nature and that under proper conditions in nature there may be a series of race variations similar to those found in domestication. Perhaps divergence in nature is not quite so rapid or so extreme as it is when controlled by the fancy of the breeder, but the same general facts hold true. In nature as well as under domestication, races are undergoing a constant series of changes, sometimes slow, and sometimes rapid.

Race variations must be variations of the germ plasm. Individual variations, as we have seen, will affect the body of the individual but will not affect the germ substance. From this it follows that individual, acquired variations will not be transmitted by heredity and will therefore have no lasting effect on the race. On the other hand, if the race is to undergo a change, as we have just seen that it does, this must be due to modifications in the continuous germ substance. Hence it follows that the only variations that can continue in the race and can be carried on for successive generations, are those that affect the germ material itself. Race variations are therefore necessarily germ variations.

The Divergence from Centers.—A little thought will show that the result of divergence of the descendants of any type in different directions will, in the end, produce extremely wide diversity among animals and plants. If the descendants of any animals diverge in two directions, and then later their descendants again diverge from each other, and if this process goes on indefinitely, it becomes evident that in the course of time the descendants of the original type will become widely unlike each other, and will show great variation from primitive forms.

Such has been the history of animals and plants. So far as we can learn of that history, it has always been one of **divergence from common centers,** the process being repeated over and over again in successive ages, until finally there has resulted the great diversity of organisms that people the world of to-day.

At the beginning of life in the world there was, apparently, no difference between animals and plants. We have already seen that some organisms so closely resemble both groups that we cannot say whether they are animals or plants. Possibly some such organisms were the first to inhabit the world. As progress continued, however, the descendants of these original forms of life diverged from each other along two great lines, one of which acquired the habit of living upon the other. The original form of life must have been capable of utilizing the mineral ingredients in nature, possibly like the green plants of to-day. Whether the original organisms were capable of carrying on photosynthesis we do not know, but in some way they must have been able to utilize minerals. However that may be, their descendants diverged into two groups, one group acquiring the green coloring matter and the power of utilizing carbon dioxid and sunlight and, by means of chlorophyll, building up starch, thus giving rise to plants. The second group of descendants, losing this power of utilizing minerals, and acquiring the power of feeding upon the materials which were manufactured by the first group, developed into the kingdom of animals.

After plants and animals were thus separated and each had developed for a time along its own line, some of the plants lost their chlorophyll and acquired the habit of depending upon other plants for food, thus becoming the *Fungi*. As the history of the world progressed, each of the two great types thus started continued to repeat the history of divergence. Age after age the descendants continued to separate into different lines, until the modern world was finally produced, with its endless series of different forms, all having been derived from common centers by descent with divergence.

CHAPTER XVIII

THE ORIGIN OF THE LIVING MACHINE: ADAPTATION; THE FORCES OF ORGANIC EVOLUTION

ADAPTATION

Meaning of Adaptation.—One of the most striking facts of the organic world, resulting from heredity and variation, is the adaptation of animals and plants to their environment. By this term is meant that the parts of each animal and plant are so particularly fitted to the conditions of its life that it seems as if they were intelligently fashioned with this end in view.

A few illustrations will make the matter a little clearer. The tree, with its roots extending under ground, with its branches growing into the air and bearing the broadly expanded leaf surface for the purpose of absorbing air, is evidently exactly adapted for its life in the soil and in the air. The roots are mechanically built so that they can push their way through the soil; the stems are rigid enough to support the heavy branches, and the leaves are broad and thin and of exactly the proper shape to absorb the largest amount of air. The wing of a bird is an example of adaptation; for its structure, its shape, the lightness of its bones, its ability to expand its feathers, the delicate manner in which the parts of the feathers are attached to each other, are all admirably adapted to an organ whose function is to support the bird in the air. The bird's feet are a beautiful instance of adaptation, since wading birds, swimming birds, and scratching birds have feet plainly adapted to their peculiar

FIG. 140.—THE PENGUIN, A BIRD ADAPTED FOR LIFE IN THE WATER

habits of life; Figs. 140 to 143. The white fur of the polar bear is an adaptation to its life habits in the north on the ice sheets; for not only does the heavy hair serve as a warm covering

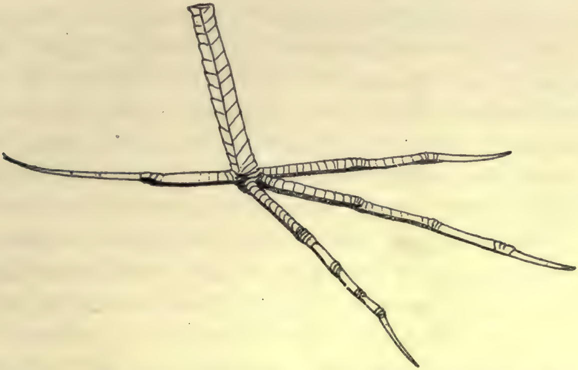

FIG. 141.—THE FOOT OF A BIRD ADAPTED FOR WADING IN MUD

to protect the animal from the cold, but its color at a distance is hardly to be distinguished from the white ice, and thus protects the bear from observation. The marvelous tongue of the

FIG. 142.—THE FOOT OF A BIRD ADAPTED FOR SCRATCHING

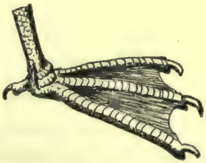

FIG. 143.—THE FOOT OF A BIRD ADAPTED FOR SWIMMING

butterfly is adapted for sucking the honey from flowers. The honey in the flower is at the bottom of the long corolla, and unless the butterfly had this long tongue to insert within the

corolla and thus reach the honey, it would not be able to utilize this food. Each butterfly is provided with a tongue sufficiently long to obtain the honey from the particular kind of flower upon which it feeds. The marvelous structure of the human hand, with its wonderful mobility, its delicate sensations, its great power of muscle movement, is clearly adapted for use as an organ of prehension, and one might believe, as has been vigorously argued, that it was especially made by an intelligent designer for the conditions of life in which man lives.

The principle of adaptation is found everywhere in nature, all animals and plants being more or less adapted to their conditions of life. Indeed, perhaps the most characteristic feature of organisms is that they are adapted to their environment, instead of being purely haphazard in their shape and structure. Inanimate objects, like stones, have no special relation to their environment, and having been produced by blind forces, are not particularly adapted to any purpose. In contrast to this, all animals and all plants show structure and functions which fit them for their environment. We may almost regard this feature of adaptation as the most universal and striking characteristic of life.

Origin of Adaptation.—How came organisms to be thus adapted to their environment? The explanation of adaptation which was for a long time regarded as satisfactory, was that each animal was made by an intelligent Creator, and exactly fitted to the environment in which it was placed. This suggestion was satisfactory so long as it was believed that each species was an independent creation. Since, however, the idea of special creation has been replaced by the belief that our present species have been derived from older types by descent, the problem of adaptation to their environment must be given a different solution. If animals have diverged from common centers, it follows that types now inhabiting different localities must have originally come from the same place, and if they were originally adapted to one locality, they could not be

especially adapted to the conditions of new localities. Hence their adaptation to a new environment must have been acquired during their growth, and not by an original special creation. The question of how the adaptation was produced, therefore, comes up with redoubled force.

More careful study, however, shows that animals are not always exactly adapted to their environment. The old idea that each organism is especially fitted for its environment is not borne out by facts. Of course living animals are always in a measure adapted to the conditions in which they live, for if they were not they would long since have been exterminated. Indeed, the history of animals shows many instances where poorly adapted animals have been crushed out of existence, leaving alive only those adapted to their environment. On the other hand, many instances are known where organisms living in one part of the world to-day are not particularly adapted to their habitat, but are really better adapted to other parts of the world if they could only get into new regions. It not infrequently happens that organisms from one country get carried by accident to another, and find the new country far better adapted to their life than their original home. For example, when the European hare was carried to Australia, it found conditions far better adapted to it than those of its original home in Europe, and it multiplied with prodigious rapidity, becoming far more abundant in Australia than ever it was in Europe. The English sparrow, when introduced from England, finding America better adapted to its life than England, multiplied very rapidly, and spread over the country. Our fields in the eastern states are filled with the so-called white daisy (*Leucanthemum*). This is a European species which, when introduced into this country, found conditions better adapted to its needs than in its original home and became far more abundant here than in its original home. These three illustrations show that although animals certainly must be adapted to the conditions in which they live or be exterminated, they are not particularly

made for those localities, since in many cases they are better fitted for other localities than their own homes. The idea that organisms were especially designed by creation to fit the conditions in which they live is thus disproved.

Adaptation the Result of Growth.—The history of organisms shows that adaptation to environment has not come suddenly, but has been the result of slow development, brought about by race divergence and evolution.

Adaptation in the life of the individual.—When the individual starts its existence it is simply a fertilized egg. It is a cell, and is not especially adapted to any particular condition of life. In its development the cell divides into many cells, and these cells assume different shapes and relations. As the organism grows, the adaptation to the environment makes its appearance. In plants, the roots soon assume a form which adapts them to the soil, while the leaves become fitted for the air; in animals, some cells adapt themselves to functions of digestion, others to the functions of motion, etc. In other words, in the life of the individual, adaptation is a matter of slow growth and comes step by step as the egg is gradually molding itself into the form of the adult. Concealed in this fertilized egg are marvelous powers which cause the egg to develop into an adult, and the powers that cause the development of the egg cause also the adaptation of the different parts to tne conditions of life.

Adaptation in the race.—There is no doubt that a similar history of growth has brought about the adaptation of the race to environment. Probably the earliest type of the plant was a single cell, adapted to life in the water but not in the soil. As the ages passed on and plants reached the land, an adaptation to this new environment slowly developed. The structures which we find in animals and plants to-day, which adapt them to their environment, were not of sudden origin in any case, but were the result of a gradual change of the older forms into newer types, more closely adapted to the new conditions of life.

As an example of such adaptation, may be mentioned the

development of the spinal column of the vertebrates during the geological ages, which is disclosed by the fossils in the rocks. When the vertebrates first appeared, apparently they had no bones, but in their backs was a rather stiff rod which gave them rigidity, this being represented by the rod in the embryo which we have already learned to speak of as the notochord (see page 286). Following along through the various strata of rocks, which represent a progressive development of vertebrates, we find that this rod in time became broken up into short sections, a condition which adapted its possessor very much better to an active life in the water. The short sections, which became the vertebræ, enabled a lateral flexing motion of the body which could not be brought about so readily if there were only a stiff supporting rod in the back. This broken series of bones, forming the vertebral column, thus adapted the animal to its rapid motion in the water. Later, when the vertebrates emerged from the water and assumed a life on the land, the type of vertebræ adapted to life in the water was no longer fitted for the condition in which the animal now lived. The vertebræ were still retained, but they acquired new connections with each other, a greater solidity and a greater rigidity, so that the spinal column could now support the body in the air. Further development of the land animals into the birds was characterized by a further change in the form of the vertebræ, which adapted the animal to life in the air, and, moreover, the vertebræ were changed in another fashion in the mammals which lived on the land. In all of these series of changes, from the original unbroken rod of the back in paleozoic times, to the complicated spinal column of the mammal, we see a successive series of adaptations. The study of fossils has made it possible to trace this series of changes in detail, and our paleontologists have quite accurately pictured for us the succession of changes that has produced this long series of race variations, bringing about an adaptation of the race, first to one condition of life and then to another, and finally ending

in the excellently adapted internal skeleton which the higher vertebrates possess to-day. All of this can be followed out in the study of fossils, and it represents only one of the many series of evolutionary changes which have occurred in the history of animals, adapting the race little by little to new conditions, or better adapting them to older ones.

Forces Producing Race Adaptation.—While biology has not yet reached a point where it considers itself capable of explaining all of the marvelous phenomena of adaptation, some of the laws that have been concerned in the production of the phenomena are fairly well understood. A primary one seems to be the law of **natural selection,** first exploited by Charles Darwin. This law and its action will be considered on a later page.

THE THEORY OF EVOLUTION

The divergence of animals and plants from common centers to produce the diversified world of to-day has been generally known under the phrase, the **theory of evolution,** or the **theory of organic descent.** The term "evolution" has a very much wider application than that which has just been given to it, since in its philosophical import it involves much more than the problem of the origin of species of animals and plants. The general theory of evolution includes the conception of the orderly development of the whole universe, by a system of natural law and force, and assumes that the origin of the world from the original nebulous mass has been, from the beginning, due to the unfolding of natural law. With the philosophical aspects of the theory we are not here concerned; but the phase of the theory that concerns the origin of modern animals and plants is one of the fundamental factors of modern biological thought. Indeed, it may be stated that modern biology did not have any real existence until, under the influence of the writings of Charles Darwin, the conception of the origin of species from common types began to be studied.

The idea which has been expressed above, that the adaptation

of organisms to their environment has been a matter of growth, is the result of the thought of the last half-century. Previous to the middle of the last century it had been assumed that organisms transmitted their characters so accurately to their offspring that they had continued from the beginning unchanged, and that species were immutable. The **immutability of species** (Lat. *im* = not + *mutabilis* = changing) had been assumed as the foundation stone of biological science, and all conceptions of nature had been based upon the idea that organisms breed strictly according to their type, without change, other than slight fluctuations back and forth from a center, and without permanent modification. The conception which we have assumed above — that not only are all organisms constantly undergoing individual variations, but that races are going through a gradual series of permanent changes, resulting in the appearance of new forms with successive ages — was quite revolutionary in thought. The belief that species were not immutable, but were constantly being transformed into new species by the ordinary processes of descent, changed the whole aspect of our attitude toward nature. During the fifty years after this conception was presented to the world for discussion, it was subjected to most hostile criticism and most bitter dispute. The objections have now, however, mainly disappeared, and it has become to-day one of the accepted doctrines of science that species are constantly undergoing changes, and that our present species have descended from older ones and will in turn develop into others. To understand and appreciate this modern conception, it is necessary to survey briefly the development of the idea and the fundamental facts that lie underneath it. In this review we will make reference only to that phase of the great theory of evolution that has to do with the origin of modern species, or to **organic evolution,** as it is commonly termed.

Early Views.—We can trace a beginning of the idea of evolution back to the scientists and philosophers before Christ. Aristotle, nearly four centuries before Christ, recognized in a

vague way the idea of a gradual succession of higher and higher forms of existence; and several other early philosophers speculated concerning the origin of living things upon the earth according to general processes of development. But these earlier ideas were soon lost sight of and it was not until the seventeenth century that any more modern ideas of the development of animals from each other were advanced. During all of these centuries, and indeed until about the middle of the nineteenth century, so far as the subject was thought of at all, the view generally accepted was that each different kind of animal and plant was an independent creation. This view crystallized into the **special creation** theory in the writings of John Ray in 1725, and became the generally accepted view of all scientists. During the seventeenth and eighteenth centuries, however, several philosophers expressed, in their writings, ideas approximating the belief that living things do not remain forever constant, but are ever going through the series of changes that we have already described as race divergence. Among those whose writings tended in this direction may be mentioned Kant, Goethe, Leibnitz, Erasmus Darwin, and others. With the beginning of the nineteenth century these conceptions began to take a more definite shape.

Lamarck.—Lamarck was a French naturalist, living in about the beginning of the nineteenth century, and was well versed in botany and zoölogy. He formulated a clearly defined doctrine of descent, and was the first of the modern scientists who had any conception of the theory of evolution. Lamarck believed that the fossils found in the rocks were the ancestors of animals living to-day, and that the organisms of the present world have been derived by descent from those that lived in previous years. The changes that had taken place in their structure he believed to have been slow and gradual, but continuous, and produced by a variety of causes which he specified, and which have received the name of **Lamarckian factors.** The chief of these causes were the following:—

1. *The direct effect of the environment* acting upon animals and plants, modifying them, generation after generation.

2. *New physical needs*, necessitating new conditions of life; these new conditions producing changes in the animals themselves.

3. *Use and disuse.*—It is a well-known fact that the use of any organ causes it to increase, and the failure to use it causes it to decrease in size and in efficiency. Lamarck supposed that the arms of birds became wings through continued use in this direction, and that the hind legs of snakes were lost because they were not used. This has been the most universally recognized of the Lamarckian factors.

4. The *transmission of these acquired characters to posterity.* Lamarck assumed, as everyone else assumed in his day, that *any* characteristics possessed by an animal or a plant might be transferred to its offspring. Hence any of the changes produced by the environment, by new physical needs, or by use and disuse, would be transmitted to the offspring, and, therefore, the next generation would have the body modified by the habit and environment in which the first generation lived. This would result in a constant modification of organisms, producing evolution.

There were certain other factors in Lamarck's conception which, though really part of the original theory, are not commonly included under the term of Lamarckian factors. One of these was *cross breeding*, *i. e.*, breeding together of individuals of different varieties, or perhaps even of different species, the result being an offspring different from either parent. A second was *isolation*, a suggestion that certain individuals became separated from the rest, and they and their offspring, being obliged to breed together, produced types in an isolated locality, which developed along lines different from those taken by other members of the same species in other parts of the world.

Although these Lamarckian factors are several in number, it will be seen that there is one common phase. In all it is

assumed that diversities produced in individuals as the result of the action of the environment, or of their own habits, *i. e.*, *acquired variations*, are transmitted to subsequent generations, and serve as the basis of the changes which produce race variations and evolution. Our study of heredity has shown that such variations, according to our present knowledge, are almost certainly not transmitted to subsequent generations. It is evident that the very foundation of the Lamarckian theory cannot stand, if the modern conception of heredity is accepted.

Lamarck's views were not accepted in his day. This was partly because the great French naturalist, Cuvier, one of the greatest naturalists that ever lived, opposed them strongly; and partly because the scientific world was not at that time ready to accept any such natural explanation of the origin of organisms as that suggested by Lamarck. They were, therefore, practically forgotten for a period of fifty years, during which time the idea that organisms had appeared by the process of descent had practically no followers, special creation of each species to fit its environment being the generally accepted view. A new era of thought was inaugurated in the middle of the nineteenth century by Chalmers, Spencer, and especially in 1859, by Charles Darwin.

Charles Darwin.—Charles Darwin was the grandson of Erasmus Darwin, already mentioned. In 1859 he published a book, the result of twenty years' work, entitled "The Origin of Species," which produced a revolution in thought, not only in science but also in philosophy. Darwin accepted the idea of the origin of modern organisms from earlier ones by a process of direct descent, recognizing that divergence of type from common centers has been the law of historical development of animals and plants. To this extent, therefore, Darwin followed Lamarck and the early speculators concerning the origin of animals. Darwin's method of explaining this descent was totally different from that of Lamarck, and much more in accordance with facts that could be demonstrated. According to

Darwin, the method by which new forms were produced was by the law of **natural selection.** Very briefly stated, that law is as follows:—

1. *Overproduction.*—All animals and plants tend to multiply more rapidly than it is possible for them to continue to exist. More offspring are produced by even the slowest breeding animals and plants than can possibly find sustenance in the world.

2. *Struggle for existence.*—As the result of overproduction, the individuals that are born are engaged in a constant struggle with each other for the opportunity to live. This struggle is sometimes an active and sometimes a passive one; and sometimes it is a struggle with each other for food. It is a struggle in which only the victors remain alive, the vanquished being exterminated without living long enough to leave offspring.

3. *Variation, or diversity.*—All animals and plants show a large amount of diversity among themselves, and, as a result, some must be better fitted for the struggle for life than others.

4. *Natural selection, or the survival of the fittest.*—It is a logical result of the struggle for existence that only those individuals best fitted for the struggle will be the ones, in the long run, to win in the contest. Hence the "fittest" in the long run will survive, while those less fitted to exist will be exterminated in the merciless struggle for existence.

5. *Heredity.*—By the law of heredity, individuals transmit to their offspring their own characters. Hence if one individual survives the struggle for existence by virtue of some special characteristic, it will transmit this characteristic to its offspring. The offspring will inherit it, and in the course of a few generations the only individuals left alive will be those that have developed the favorable characteristic in question, while those that did not develop it will be exterminated by the law of natural selection.

As the result of these five factors working together, Darwin supposed that there would be a constant accumulation of favorable characters, each generation being to a slight extent an

advance over the last. The struggle for existence and the survival of the fittest are repeated generation after generation, and in each successive generation the only members to survive will be those with qualities that make them better able to contend in the struggle for existence than their rivals. Hence every individual character which gives its possessor any slight advantage over its rival will be sufficient to enable its possessors to survive the struggle for existence, by bringing about the extermination of the less fortunate individuals that did not have the favorable character in question. This character will be transmitted to subsequent generations, when the struggle will be repeated again, and once more the best characters of the next generation will be selected. As this goes on without cessation age after age, there will be a constant accumulation of favorable characters, and thus the race will in general constantly advance.

Natural Selection and Adaptation.—This law of natural selection is especially well fitted to explain the marvelous adaptations of organisms to their environment. Since the different members of any species of animals or plants are not alike, it will follow that at any period in the history of a race, some individuals will be more closely adapted to their environment than others. Since there is always an overproduction of individuals, so that many more are born than can live, it will follow that the individuals best adapted to their environment will be the ones that will survive, while those less adapted to the conditions of life will be the ones to be exterminated in the struggle for existence. Hence it will follow that at the close of any generation the individuals left alive will be those that have the most favorable adaptation to environment. These will necessarily be the parents of the following generations, and, by the law of heredity, the next generation will inherit the characteristics of these parents and will be, on the average, a little better adapted to the environment than the last generation. If this process is repeated generation after generation, it will follow that each generation

will be slightly better adapted than the last. By an accumulation of the improvements which thus appear accidentally, there will be developed, as the generations pass, a closer and closer adaptation to conditions. The final result is a better adaptation to conditions, and a gradual change of type and production of new species.

Acquired and Congenital Characters Affecting Natural Selection.—In the form stated above, and as at first conceived by Darwin, the characters which are chosen by natural selection, and upon which the advance of the race is based, might be either acquired characters, such as those upon which Lamarck based his theory, or they might be congenital characters, which are in the germ plasm and essentially due to variation in the hereditary substance. Darwin did not sharply separate these two types of variation, although he recognized them both. Darwin thought that the advancement of type was produced primarily by the natural selection of such characters as were born with the individual, *i. e.*, congenital characters. He also believed that, to a certain extent, acquired characters, which were produced in the animal either by the direct effect of the environment or by use or disuse, could be transmitted and might thus affect posterity and have an influence in changing the type. Darwin did not believe, as did Lamarck, that these acquired characters were the primary factors in producing divergence of type, but thought they might be secondary ones, the primary factor being the selection of most favorable congenital variations.

Weismann.—The discussion of Darwin's theories continued vigorously for a quarter of a century, until his views of descent were quite generally accepted, although with various opinions as to the *efficiency* of his law of natural selection. In 1884 appeared the essay of Weismann "On Heredity," which put a totally new aspect on the whole problem. His theory of heredity, already described, was so simple, and so readily obtained confirmation by direct observation, that it soon acquired almost

universal acceptance. With the acceptance of Weismann's theory, it was no longer possible to look upon acquired characters as transmitted to posterity. As a result, the Lamarckian factors were of necessity thrown overboard, since they all involved the inheritance of acquired characters. It was no longer possible to believe that the direct effect of the environment upon the individual, or the effect of the disuse of organs, could have any influence upon posterity; and as rapidly as Weismann's theory of heredity received acceptance the so-called Lamarckian factors were discarded, until to-day they are not generally regarded as factors in producing race variation. The adherents of Weismann have thought that the only possible factor left to produce evolution was the natural selection of the congenital variation. Congenital variations, since they are due to variations in the germ plasm, will be transmitted; and the natural selection of these congenital variations will remain as the great factor in the development of type. Indeed, the followers of Weismann took this extreme view and held, and still hold, that the only factor which has produced race evolution has been the natural selection of those characters which start as variations in the germ substance. But the dispute between the followers of Lamarck's older views and Weismann's new views has never yet been positively settled. Some naturalists accept Weismann's views *in toto;* others have not regarded them as sufficiently well demonstrated; while quite a number of prominent biologists, including Spencer, Packard, Cope, and others, have held to a modern form of Lamarck's views, believing that in some way, and under some circumstances, acquired characters might have influence upon the offspring and therefore might direct the line of race divergence. The question has not been definitely settled; but at the present time the balance of evidence seems to be against believing that acquired characters are transmitted, and therefore against the retention of any of the so-called Lamarckian factors, that are based upon the direct action of the environment upon the individual.

The Mutation Theory.—One of the essential factors of the Darwinian theory was that the change of species was produced by the selection of *minute* diversities, such as the slight differences found among animals and plants of the same species. It was argued by Darwin that in the struggle for existence, when the majority must be exterminated that the few may live, even the slightest differences in structure, shape, body, color, or habits would be sufficient to determine the question of life or death. If these slight differences could accumulate, generation after generation, they would in time become great; and thus, according to Darwin, the great differences between type were produced by the accumulation and heaping up of *minute variations.* To many of the more recent students of this subject it has not seemed plausible that such minute differences could accomplish all that Darwin claimed for them. Many objections to Darwin's ideas on this line have been expressed, and have finally found voice in a more recent conception of the conditions which have produced the evolution of the living world. This new idea is the **mutation theory** (Lat. *mutare* = to change), and is commonly associated with the Dutch naturalist, DeVries, although a number of others have shared in its origin and development. DeVries based his views upon observations made in a field of primroses, where he kept thousands of individuals under observation. As the result of these observations, he came to the conclusion that new types of plants are appearing constantly in nature; but that they do not arise, as Darwin had supposed, by the accumulation of little changes one generation after another, but suddenly, and, as a rule, in single steps. In his field of primroses, growing side by side, he found several distinct types, absolutely different from each other and with no intermediate steps between them. They came, not as the result of the accumulation of little steps, but suddenly, in a single generation. Moreover, by isolating and experimenting with them, he found that the new characters, which had thus appeared, bred true, *i. e.*, remained fixed in the race.

From this series of observations, extended in other directions by many other observers, has been developed the theory of mutation. This theory is, in essence, that new characters do not, as a rule, appear simply as slight diversities found between different individuals of the same species, but as characters of considerable extent at a single birth. New features of the race are thus sudden in their origin instead of gradual, as had been supposed by Darwin and also by Lamarck. According to this theory there are two types of variation among organisms: 1. **Individual variations,** spoken of above as the diversities which are shown between different individuals, and which come and go in a haphazard fashion, having no part to play in the change of the race. These may be acquired characters; at all events they are not impressed upon the germ plasm. 2. **Mutations,** which probably start with the germ plasm; Fig. 144. These variations may be large or small, but whenever they appear they are at once fixed in the race. Inasmuch as they are part of the germ substance, they will be handed on to the next generation and remain, therefore, as a permanent inheritance of the race. According to the mutation theory, these sudden large changes have brought about the race divergence. The theory of mutation, therefore, abandons Darwin's idea of the accumulation of the minute diversities, and replaces it with the idea that the steps in evolution may be larger and may be taken suddenly. It is, of course, evident that this new conception of mutation is perfectly consistent with Weismann's view of heredity.

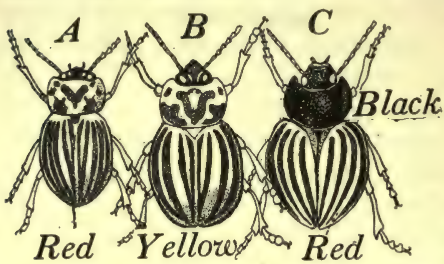

FIG. 144. — MUTATIONS SHOWN BY THE BEETLE *LEPTINOTARSA*

A and *C* are mutants from the original form *B*. The actual differences are greater than appears in these figures because of great differences in color.

(Tower.)

Mendel's Law.—Accompanying the development of the theory of mutation, there has been brought prominently to view a somewhat new view of the laws of heredity, perfectly consistent with Weismann's theory, but explaining its method of action. Darwin in his discussion assumed that the offspring of two parents, since it could not be like both, would, in general, be halfway between the two. Even the slightest familiarity with the laws of heredity is enough to show that organisms inherit from both parents, and it has generally been assumed that they inherit, or may inherit, equally from both. It is, however, manifestly untrue that the offspring is always midway between its father and mother, inheriting equally characters from each. The laws of heredity are much more complex than this, for it frequently appears that an organism inherits mostly from *one* parent, the characteristics of the other hardly reappearing in the offspring. An attempt to bring some of these facts into a general law has resulted in what is called **Mendel's law of heredity.** Mendel published the result of his work originally in 1866, but it attracted no special attention for nearly forty years, when it was revived by modern students in 1900. Since that time it has been subjected to extensive experiment, and has produced results of very great practical value in controlling and directing breeding experiments with animals and plants. Mendel's law is somewhat complex and difficult to understand, but the essential features of it are as follows:—

Unit characters.—It is an assumption of Mendel's law that, in many cases at least, different characters of animals are **unit characters.** By this term is meant that those characteristics are handed to the offspring as single units, which are inherited by the offspring *in toto or not inherited at all.* They cannot be halved or reduced in total characteristics. In other words, if the offspring inherits one of these unit characters, it inherits it in full. Even though the offspring should come from two parents, one of whom possessed the character in question, while the other did not, the offspring would either inherit it as a whole

or not at all. For example, two varieties of peas are known, one of which has short pods and the other long pods. If they are crossed the offspring are either short-podded or long-podded, but not midway between the two. Very many other characters have been tested out experimentally and found in the same way to be inherited as unit characters.

Dominant and recessive characters.—Mendel's law further points out that some of these unit characters are much more likely to reappear in the offspring than others. It frequently happens that of two opposite characters, one is much more likely to appear in the next generation than the other. Those that are most likely to reappear are called, in this terminology, **dominant** (Lat. *dominari* = to rule), while other characters that are more likely to disappear in the first generation, are called **recessive** (Lat. *recessus* = receding). These recessive characters, even though they do not appear in the first generation of offspring, are not necessarily lost. The offspring may contain within its body the germs of these characters, but they may remain dormant, not appearing at all in the first generation. In subsequent generations these recessive characters may reappear; thus recessive characters, which are present in one generation, may disappear in a following generation, to reappear subsequently in the later generations.

Law of inheritance.—The specially valuable contribution of Mendelism is the formulation of a law in accordance with which these dominant and recessive characters reappear in subsequent generations. That law is briefly as follows: When we cross with each other two individuals, one of which has a dominant character, while the other has its opposite as a recessive character, *all* of the offspring in the first generation show the dominant characteristics. But although *showing* only the dominant characters they actually contain a mixture of dominant and recessive characters. This is shown by the fact that if these individuals now are bred together, in the next generation, which we will call the second generation, only three-fourths of the off-

spring will show the dominant character, while one-fourth will show the recessive character. If now the individuals showing this recessive character are bred with each other, *all* their offspring will show the recessive character, the dominant character having totally disappeared from them, never to occur again in any subsequent generation. This race is then a *pure recessive type*, from which all of the dominant characteristics have been eliminated. All of the other three-fourths of the second generation show the dominant character only. But tests, similar to the above, prove that only one of these is purely dominant. The other two-fourths, although in them the dominant character only is evident, are really mixed, containing both dominant and recessive characters. This is shown by the fact that if they are crossed, three-fourths of their offspring will again show the dominant character and one-fourth will show the recessive character. This process may then be repeated indefinitely.

An illustration may make this clearer. Among mice the color gray is dominant, while the color white is recessive. If white and gray mice are bred together, the first generation of offspring will be all gray. If these gray animals are now bred together, in the second generation three-fourths of the offspring will be gray but one fourth will be white. If these white animals are bred together, their offspring will all be white and will continue to breed white offspring indefinitely, no gray mice ever subsequently appearing in their progeny. They constitute a *pure white race.* If the other three-fourths, which are gray, are bred together, one of the three-fourths will continue indefinitely to produce gray offspring, no white ones appearing. In these the white characteristic has been eliminated entirely, and they form a *pure gray race.* But the other two-fourths, when bred together, prove to contain both white and gray characters, and among their offspring one-fourth will show the white fur and the other three-fourths the gray fur. If again tested in the same way, the white animals will be found to produce pure races of

white with no mixture of gray fur; one of the other fourths will be found to be pure gray races with no mixture of white, and the other two-fourths will again prove to be a mixed race containing both white and gray characters. This process may then go on indefinitely.

The further details of this law are too complicated to be followed out in this place, but from the law it is possible to calculate approximately how many of the offspring at each generation will show recessive, and how many dominant characters. This law has been of great value in directing breeding experiments, and breeders who are trying to produce new varieties of animals and plants find the law extremely useful in controlling their experiments toward definite ends. Mendel's law has thus shown that the inheritance by the offspring of the characters of the parents is not a pure matter of chance, but is controlled by definite laws. While we do not yet fully understand these laws, the fact that some of them have been discovered gives promise that we may, in time, be able to control the process of inheritance far more accurately than hitherto.

It is not believed by those who have worked on Mendel's law that all characteristics of organisms are thus unit characters and are transmitted *in toto* or not at all. Some characters appear to **blend,** as for example the cross between the white race and the negro, the offspring of such crossing being neither white nor black but mulattoes, a mixture midway between the parents. Hence the color of the human skin is probably not like the white and gray color in mice, a character transmitted by the law of Mendel. This law of Mendel has, however, been a great contribution to science in showing that large numbers of characters or organisms are unit characters, and are transmitted according to definite laws that may be clearly formulated.

We may say, in concluding the general subject, that modern biological science recognizes the principle that race divergence has been the law of life, and that the evolution of modern types

from earlier ones by descent has been the method by which the present world was produced. Further, the laws formulated by Darwin, DeVries, and Mendel, together with Weismann's theory of heredity, all fit together to explain the method of this evolution. New variations have appeared suddenly, at least in many cases, as germ variations (mutations), and then have been transmitted to the offspring as unit characters by Mendel's law, some of the offspring receiving the new characters, while others do not; but if inherited they are inherited as unit characters. Next, the law of natural selection comes in and selects those individuals which have received useful mutations. Selection then "fixes them" in the race by eliminating individuals with characters less useful than those possessed by the survivors. As a result of all these factors working together the race advances.

CHAPTER XIX

CLASSIFICATION AND DISTRIBUTION

EVEN the slightest familiarity with organisms will disclose striking similarities between some forms and great differences between others. The frog is clearly quite like the lizard and much like other vertebrates, but very unlike the earthworm. These points of likeness are the basis upon which organisms are classified.

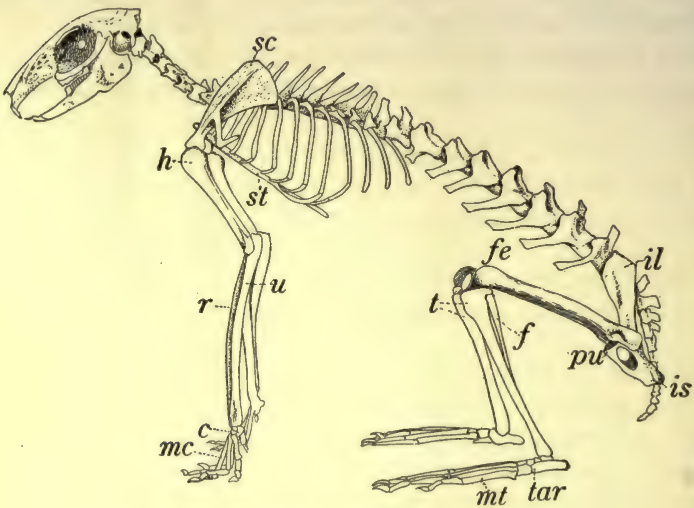

FIG. 145.—THE SKELETON OF A RABBIT

c, carpals; *f*, fibula; *fe*, femur; *h*, humerus; *il*, ilium; *is*, ischium; *mc*, metacarpals; *mt*, metatarsals; *pu*, pubis; *tar*, tarsals; *r*, radius; *sc*, scapula; *st*, sternum; *t*, tibia; *u*, ulna.

Homology.—The likeness between organisms is of two general types. The first is likeness in *structure*, which is called **homology** (Gr. *homos* = like + *logos* = ratio). It is frequently found that

animals which appear quite unlike are really built upon the same plan of structure, differing only in the manner that the plan is carried out. For example, the frog possesses a spinal column made of vertebræ, and two pairs of legs attached to the body by girdles, each containing a certain number of bones. The rabbit (Fig. 145) has a skeleton based upon the same type. It also possesses a spinal column made of vertebræ, with two pairs of appendages attached by girdles to the axis of the body; and each appendage is made up of bones which can be compared, bone by bone, with those in the appendages of the frog. If Figure 145 is compared with Figure 88, this similarity can be seen and followed out in very close detail, nearly all of the bones of the frog being represented in the skeleton of the rabbit. This similarity is found in spite of the fact that the two animals are so unlike in general appearance and in habits. One lives in the water and uses its legs for swimming and hopping; the other lives on the land, using its legs for support. But although built for different purposes, the skeleton of these two animals is evidently based upon the same plan. Figure 146 shows another example of similarity in structure representing the hand of man, *C*, and the corresponding fore foot of four other animals. Although the hand of man is used for a totally different purpose from that of the fore legs of the horse, the ox, or any of the other animals represented, it is evident that they are built upon the same plan of structure. In each there are a radius and ulna, and a series of wrist and finger bones. There are differences, it is true: while

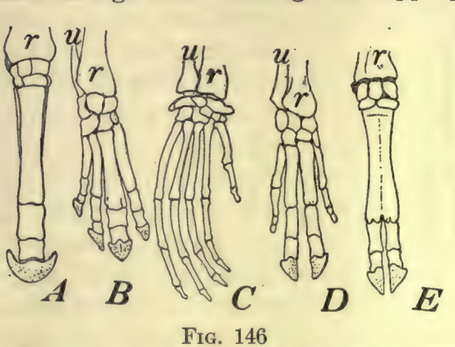

FIG. 146

The skeleton of the hand of man, *C*; and the fore feet of a horse, *A*; a rhinoceros, *B*; a pig, *D*; and an ox, *E*. *r*, radius; *u*, ulna. The other bones are not named but may be easily compared.

man has five fingers represented, the others have lost some of these fingers, and one of them, the horse, *A*, has left but a single finger with the rudiments of two others. That these other fingers have been lost has been proved by the study of the paleontology of these animals; for by tracing back their history through fossils it is found that the ancestors of the horse had at first five fingers, with a type of hand similar to that of man; later they had three and finally only one finger. This similarity in the structure between the frog and the higher animals is shown in other parts of the body besides the bone. Figure 147 represents a section through the body of a cat, giving a diagrammatic representation of the relation of the organs in the upper part of the body. This can be compared directly with the anatomy of the same region of the body of the frog, and while there are many differences in detail, the general structure is evidently the same. The spinal cord with the brain is found on the dorsal surface of both animals; the mouth, nostrils, larynx, lungs, and œsophagus are, in essential features, identical. Thus it is evident from these comparisons that the

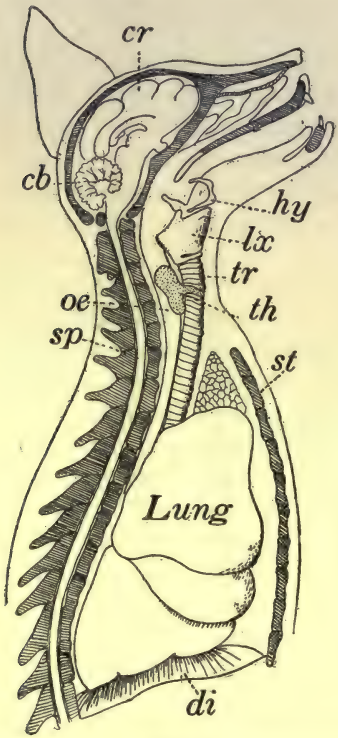

FIG. 147.—A MEDIAN VERTICAL SECTION OF A CAT, SHOWING DIAGRAMMATICALLY THE RELATIONS OF THE ORGANS

cb, cerebellum; *cr*, cerebrum; *hy*, hyoid; *lx*, larynx; *oe*, œsophagus; *sp*, spinal cord; *st*, sternum; *th*, thyroid gland; *tr*, trachea.

frog, the cat, and the rabbit are built upon the same general plan, which is carried out in different ways in different cases. In other words, we have in these animals a likeness of structure quite independent of differences in the general purposes for which the various parts of the body are used. A comparison of Figure 97 with Figure 148, representing the eyes, respectively, of the frog and of man, will show that this similarity is carried out in the details of structure, even of the smaller parts. Although differing in some minor points, it will be easy to trace in the eye of the frog the same parts that are present in the human eye. It is perfectly clear that these two organs are based upon the same plan and are identically planned structures.

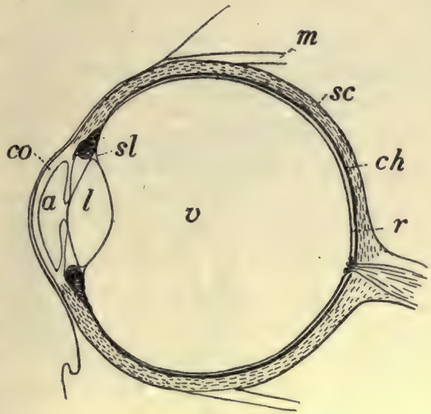

FIG. 148.—A VERTICAL SECTION OF THE HUMAN EYE

a, aqueous humor; *ch*, choroid; *co*, cornea; *l*, crystalline lens; *m*, muscle; *r*, retina; *sc*, sclerotic; *sl*, suspensory ligament; *v*, vitreous humor.

Such similarities in structure are not by any means confined to animals with a bony skeleton, but may be found among all groups of animals. Figure 149 represents a worm, which, by comparison with the figures of the earthworm in Chapter VIII, shows a similar structure in spite of differences in detail. The earthworm bears at first sight little resemblance to the worm shown in Figure 149, the latter having external tentacles and gills, neither of which is found in the earthworm. But it will be seen that both are made up of a series of similar segments, and that in general shape they are the same. If their internal anatomy is compared, both are found to have a similar alimen-

tary canal, similar circulatory, nervous, and excretory systems, and all other parts of their anatomy are essentially alike. Such a likeness in structure is sometimes found in quite unexpected places. One would hardly expect, for example, that the arm of man, the fore leg of a horse, the wing of a bird, the fore leg of a frog and the fin of a fish would be identical structures, since they vary so much in shape and function; but they are all found to be homologous.

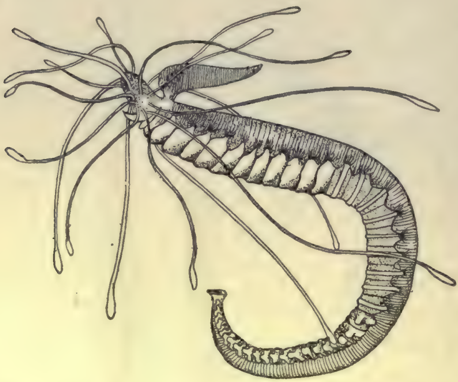

Fig. 149.—A segmented worm related to the earthworm, but having tentacles and gills

Analogy.—A second type of likeness is similarity in function, irrespective of structure. It not infrequently happens that different animals develop organs of similar functions but of totally different structure. In this case they are said to be **analogous** (Gr. *ana* = according to + *logos* = ratio) but not homologous. For example, the butterfly and the bird have both developed wings for flying, and their wings are hence analogous. They are of similar shape and are used much in the same way; but the wing of the bird is made of bones, muscles, nerves, and feathers, while the wing of the butterfly has none of these parts, being simply an outgrowth of the skin containing air tubes. It is not homologous with the bird's wing, in spite of similarity in shape and function. The wing of the bird is, however, both analogous and homologous with the wing of the bat, since both are used for similar purposes and both are made of similar bones and muscles, nerves and blood vessels. As another

example of analogous organs, may be mentioned the teeth in the mouth of vertebrates and the peculiar teeth found inside the stomach of the lobster. These organs are both used for grinding food; but they are not homologous organs, since their structure is so different. The teeth are bony organs arising from the bones of the skull, which are themselves developed from the mesoderm of the embryo; the teeth of the lobster are of horny texture, and are developed from the ectoderm of the embryo which is folded inward to line the stomach. Numerous other examples of analogous organs might be given, for it frequently happens that different animals use for the same purpose organs that have quite a different origin and structure.

Explanation of Homology and Analogy.—Analogous organs sometimes show much similarity, as in the shape of the wings of the bird and butterfly, and sometimes very little. When they do show a likeness it is explained by the fact that similar necessities of life have forced the development of similar structure. For example, both the vertebrates and the lobster are obliged to masticate their food, and both have consequently developed hard cutting and grinding surfaces for the purpose. There is, therefore, some similarity in the form of the organs; but there is no necessity for similarity in structure, and in the two cases different parts of the body have been utilized for the purpose.

The likeness between homologous organs, however, requires a very different explanation, because here we find a similarity in structure *in spite of differences in function.* We cannot explain the similarity in structure by any similarity of conditions. Although the wing of the bird and the arm of man are adapted to wholly different functions and have developed different shapes and motions, they are, in spite of this difference, formed upon the same plan, with an identical structure. The explanation must be something more fundamental than mere similarity in use. Naturalists to-day account for likeness in homologous organs by the **theory of descent**, saying that two animals with homologous

organs owe their likeness to the fact that they have descended from a common ancestor possessing such an organ. The bird, the dog, and the monkey show homology in the wing, fore leg, and arm, because they have descended from a common ancestor, whose fore appendage possessed a certain series of bones and muscles, and, therefore, all its descendants have, by inheritance, retained these same bones and muscles. The differences between the members in question have been brought about by the fact that they were used for different purposes, and thus were slowly modified in shape, although they still retained a fundamental likeness in structure.

CLASSIFICATION (TAXONOMY)

Individuals.—As we look upon nature to-day, we find only individual organisms, each isolated from all others, and allied only with its parents. But the most superficial examination shows that some individuals have resemblances to each other, while others are very unlike; and it is evident that organisms can be arranged in groups showing more or less likeness to one another. Such a grouping is called **classification.** The general plan of such classification into groups is as follows:—

Species.—When we find a large number of individuals resembling one another so closely as to be practically identical, we speak of them as belonging to a single **species.** For example, the common *dandelion,* which is widely distributed over the world, is made up of countless numbers of individuals; but they are essentially alike, in root, in stem, in leaf, in flower. We therefore speak of them all as constituting a single species. So too is the *horse* a distinct species, and the *ass* another. To give a definition of just what is meant by species is impossible, since no one knows just what is meant, and the word perhaps does not always have the same meaning. That the individuals of a species are not always exactly alike is evident from facts already mentioned concerning the great variations among different *pigeons* and *dogs.* Such great variations as those pre-

viously mentioned among dogs are very exceptional, for as a rule the members of the same species are closely alike.

Just what biologists mean by species, and just what line they would draw to separate two species from each other, cannot be stated. It is quite impossible to say how unlike two animals must be to constitute two species, since sometimes, as with pigeons, members of the same species may be very unlike, while in other cases, as with sparrows, animals belonging to different species are very closely similar. It has been quite common to regard all animals that can breed together and produce fertile offspring, as belonging to the same species. But this is not an accurate definition of the term, for there are many animals, so different from each other that they certainly deserve to be ranked as different species, but which can breed together. Nor can we get any idea as to the meaning of the term "species" by studying the number of similar individuals. Some species are composed of an immense number of individuals, as in the case of the dandelion; while other species comprise very few animals, sometimes only one or two having been found. Sometimes, too, the organisms belonging to the same species show a number of sub-groups, and the biologist calls them **sub-species,** or **varieties.** All of these facts show that no naturalist can at the present time exactly define the term "species," or state definitely how species may be separated from each other. When we recognize that new types are constantly arising from old ones by the process of divergence, it will be seen that we could not always expect to draw sharp lines separating the new and the old types that have arisen from a common center. But although naturalists are not able to define the term accurately, or separate the species strictly from each other, species are always recognized and form the starting point for classification.

Genera.—A little study shows at once that some species have a much greater resemblance to each other than they do to others. For example, naturalists recognize the domestic cat as constituting one species, and the wild cat as a second. But it is quite

clear that the *wild cat* and *domestic cat* show greater resemblances to each other than they do to *tigers, dogs,* or *wolves.* Moreover, it is evident to anyone in the slightest degree familiar with animals, that *lions, tigers, leopards, wild cats,* and *domestic cats,* although unlike each other, and recognized by naturalists as belonging to different species, have many points of resemblance to each other. They have the same general stealthy habits, the same kind of toes and feet, and they are much more closely allied to each other than any one of them is allied to the *dog* or the *wolf.* Naturalists, therefore, group all of these species together under one group which they call a **genus** (pl. **genera**).

In naming any species, two names are commonly used, the first of which is the name of the genus, the second that of the species. For example, *Felis* is the name given to the whole genus of cats. *Felis domestica* is the domestic cat; *Felis leo* is the lion; *Felis bengalis,* the bengal tiger; *Felis canadensis,* the Canadian lynx, etc. So, too, *Viola* is the genus name of all the violets; *Viola blanda,* of the white violet; *Viola cucullata,* of the common blue violet, etc. If the species should happen to have more than one variety or sub-species, a third name may sometimes be added to indicate the particular variety of the species. As a rule, however, two names only are used.

Families.—Extending observation a little farther, it becomes evident that many genera show close resemblances which mark them off distinctly from other animals. As a result, naturalists group genera together into a larger group, which they call a **family.** A family sometimes may contain only a single genus; it may contain two or three or a large number of genera.

Orders.—In the same way, families are grouped together to form larger groups, which are called **orders.** For example, the various *cats* already considered have certain points in common with the *dogs, wolves, bears, seals,* and *walruses.* In all of these cases the teeth are especially adapted for cutting flesh, and the animals are flesh eaters. There are very many genera among

them, and a number of different families; but all agree in the living upon flesh, and all show certain points of likeness in the structure of the feet and the skeleton, which place them in a group by themselves, distinct from animals that live upon vegetable foods. All of these flesh-eating animals are, therefore, grouped together into an order called the **Carnivora.**

Classes.—In a similar way, different orders can be arranged in still larger groups. For example, although there are many points of difference between the carnivorous *cat,* the herbivorous *buffalo,* the gnawing *rabbit,* the flying *bat,* and the gigantic marine *whale,* still they all agree in one fundamental character. In all of these orders the females have **mammary glands** and nourish their young by means of milk, a characteristic which is totally lacking in fishes, reptiles, and birds. It is evident, therefore, that all of these milk-producing animals may properly be classed together under one head. Such a group we then know as a **class**; in this particular case we name them the **Mammalia.**

Phyla.—Extending our observations still farther, we find that all of the animals mentioned, together with *fishes, reptiles, amphibia,* and *birds,* resemble each other in having bones, which none of the rest of the animal kingdom possesses. The *insects, clams,* etc., never have bones, but have other characteristics of their own. It is evident, therefore, that all animals possessing bones may be grouped together as distinct from other types. This produces a group that we know as a **phylum** or **subkingdom.** In this particular case we name the phylum the **Vertebrata.**

Kingdoms.—Now if we sweep our glance over the whole organic world, we find that it is divided into two groups, the animals and the plants. These large groups we call the **animal kingdom** and the **vegetable kingdom.**

Thus it is seen that the whole organic world is divided into *kingdoms, phyla, classes, orders, families, genera,* and *species.* Occasionally we recognize intermediate groups; for instance,

between the family and the genera there are sometimes recognized what we call sub-families, between the classes and the orders we find *sub-classes*, etc.

THE SIGNIFICANCE OF CLASSIFICATION

Why should there be a classification? — As soon as we recognize the principle of divergence from type it becomes evident that the classification of animals has a meaning. Classification means *history*, and if we could get a perfect classification we should have pictured the history of organisms. The first step in the development of the organisms of the world was the divergence of animals and plants from one another, thus forming the two kingdoms of plants and animals. Then the process was repeated in each kingdom, where there appeared a still further divergence, a number of different lines of descent starting from common centers, giving rise to the various sub-kingdoms. Again each of these broke up into other lines of descent, and the smaller groups thus made their appearance. Thus types continued breaking up and branching out in various directions, giving rise to a classification which may be compared to a tree, the trunk being the original type of organisms, the various large branches representing the first lines of divergence from the original stock, while the numerous subordinate branches represent the successive types that appeared, by the same general law. The minute twigs at the end of the branches are the species of to-day, and they are all connected by this line of descent with the original trunk.

The classification of animals is the attempt to reconstruct this treelike arrangement of organisms according to their historical relationship. The members of the same species are supposed to have had a common ancestor in a fairly recent period; the different species of the same genus had a common ancestor a little farther back in history; the different genera of the same family had a still earlier common ancestor; the families of the same order had their connecting point farther back still, and so

on through the whole series, until we get back to the common starting point, or the common center from which all animals and plants diverge. Classification is thus an expression of history.

The following is an outline of the classification of animals and plants. The classification accepted by science is ever undergoing changes, as a more complete knowledge of relations is obtained, and the classification accepted to-day is different in many respects from that adopted a generation ago. In turn, the classification used to-day will doubtless be modified by future study, until it becomes practically perfect. But even though we recognize that it is not yet perfect, it is quite necessary to have such a classification in order to understand the living world. It must not be inferred that our present classification represents an accurate history of organisms. The classification that biologists are aiming at is a *genetic* one, *i. e.*, one that represents *actual relationships*, and to a considerable extent the classification outlined below does represent such relationships. But the difficulties of determining the actual history of organisms have been so great as to seem in some respects almost insurmountable. The classification of organisms given to-day represents, therefore, only an attempt to express genetic relationships, and is recognized as being only in part successful.

AN OUTLINE OF THE CLASSIFICATION OF THE LIVING WORLD

THE PLANT KINGDOM:

Phylum I. **THALLOPHYTA**: plants without distinction of root, stem, or branch.

- Sub-phylum 1. **Algæ**: thallophytes possessing chlorophyll: including unicellular forms, pondweeds, seaweeds, etc.
  - Class I. *Diatomaceæ:* the diatoms (Fig. 68 *A*).
  - Class II. *Cyanophyceæ:* the blue-green algæ (Fig. 68 *C*).
  - Class III. *Chlorophyceæ:* the green algæ (Fig. 30).
  - Class IV. *Phæophyceæ:* the brown algæ.
  - Class V. *Rhodophyceæ:* the red algæ.

Sub-phylum 2. **Fungi**: thallophytes without chlorophyll: bacteria, yeasts, molds, etc.

Class I. *Schizomycetes:* the bacteria (Fig. 33).
Class II. *Saccharomycetes:* the yeasts (Fig. 32).
Class III. *Phycomycetes:* the alga-like fungi (Fig. 42).
Class IV. *Ascomycetes:* the sac-fungi.
Class V. *Basidiomycetes:* the basidio-fungi (Fig. 115).

Phylum II. **BRYOPHYTA**: the moss-like plants.

Class I. *Hepaticæ:* the liverworts.
Class II. *Muscineæ:* the mosses.

Phylum III. **PTERIDOPHYTA**: the ferns and their allies.

Class I. *Filicales:* the true ferns (Fig. 124).
Class II. *Equisetales:* the horse-tails.
Class III. *Lycopodiales:* the club mosses.

Phylum IV. **SPERMATOPHYTA**: the seed-bearing plants.

Sub-phylum 1. **Gymnospermæ**: the cone-bearing plants, pines, hemlocks, etc.

Sub-phylum 2. **Angiospermæ**: flowering plants.

Class I. *Monocotyledons:* endogenous plants.
Class II. *Dicotyledons:* exogenous plants.

THE ANIMAL KINGDOM:

Division I. **PROTOZOA**: unicellular animals.

Class I. *Rhizopoda:* animals with naked protoplasm and pseudopodia (Fig. 19).
Class II. *Infusoria:* animals with cilia, flagella, or tentacles, and usually a mouth (Fig. 21).
Class III. *Sporozoa:* parasitic animals, producing spores and having a metamorphosis (Fig. 25).

Division II. **METAZOA**: many-celled animals with a differentiation of cells.

Phylum I. **PORIFERA**: animals with no distinct mouth, but many incurrent openings: the sponges.

Class I. *Calcarea:* with a skeleton of calcareous spicules.
Class II. *Non-calcarea:* with a skeleton of silicious or horny spicules, or none.

Phylum II. **CŒLENTERATA**: animals with a mouth, but without an anus and with no body cavity.

Class I. *Hydrozoa* (Fig. 69).
Class II. *Syphozoa:* sea-nettles.
Class III. *Actinozoa:* corals, anemones.
Class IV. *Ctenophora.*

Phylum III. **ECHINODERMATA**: radiate animals, with complete alimentary canal and a body cavity.

Class I. *Asterioidea:* starfishes.
Class II. *Ophiuroidea:* brittle stars.
Class III. *Echinoidea:* sea-urchins.
Class IV. *Crinoidea:* sea-lilies.
Class V. *Holothuroidea:* sea-cucumbers.

Phylum IV. **PLATYHELMINTHES**: flat, unsegmented worms.

Class I. *Cestoda:* the tapeworms.
Class II. *Trematoda:* the flukes.
Class III. *Turbellaria:* the planarians.

Phylum V. **NEMATHELMINTHES**: round, unsegmented worms: round worms, threadworms.

Phylum VI. **MOLLUSCOIDEA.**

Class I. *Polyzoa:* sea-mats, corallines.
Class II. *Brachiopoda:* lamp-shells.

Phylum VII. **Annulata:** the segmented worms.

Class I. *Chætopoda:* bristle-footed worms.

Sub-class A, *Polychæta;* with many bristles (Fig. 149).

Sub-class B, *Oligochæta;* with few bristles (Fig. 74).

Class II. *Hirudinea:* leaches.

Class III. *Archiannelida.*

Class IV. *Gephyrea.*

Class V. *Chætognatha.*

Phylum VIII. **Mollusca.**

Class I. *Pelecypoda* or *Lamellibranchia:* bivalves, clams, oysters, mussels.

Class II. *Gasteropoda:* univalves, snails.

Class III. *Amphineura:* many-valved: chiton.

Class IV. *Cephalopoda:* with long arms: squids, cuttle-fishes.

Phylum IX. **Arthropoda:** with jointed feet.

Class I. *Crustacea:* crabs, lobsters, barnacles.

Class II. *Onychophora.*

Class III. *Myriopoda:* millipedes, centipedes.

Class IV. *Hexapoda:* insects.

Class V. *Arachnida:* spiders, scorpions, etc.

Phylum X. **Chordata:** animals with a notochord.

Sub-phylum, **Atriozoa**: body cavity opening to the exterior.

Class I. *Urochorda:* tunicates or sea-squirts.

Class II. *Cephalochorda:* amphioxus.

Sub-phylum, **Vertebrata**: animals with a vertebral column.

Class I. *Pisces:* fishes.

Class II. *Amphibia:* frogs, toads, salamanders.

Class III. *Reptilia:* lizards, snakes, turtles, alligators.

Class IV. *Aves:* birds.

Class V. *Mammalia:* mammals.

DISTRIBUTION OF ANIMALS IN SPACE AND TIME

We have already seen that while organisms are always adapted to the locality in which they live, they are frequently even better fitted for other localities, and their presence in any part of the world must be due to other factors besides fitness. The distribution of organisms on the earth's surface is controlled by three fairly well-known laws:—

1. *The members of a species usually occupy a continuous territory.* We do not find some members of a species in one locality and others in a distant region, without finding them also in intermediate territory. There are some exceptions to this law, but in the vast majority of instances each species occupies a continuous territory around a center of origin. The territory occupied will depend upon many factors of climate, for of course the habitat must be properly fitted to furnish the organism with food, water, and a proper temperature.

2. *All animals and plants can multiply with a rapidity sufficient to give them, in a comparatively short time, enough offspring to cover the face of the earth.* The rate of multiplication of different organisms varies very greatly. The codfish may produce 8,000,000 eggs per year, while the elephant produces only a single offspring in two years, and usually not so frequently as that. Among the lower animals and plants, the rate of reproduction is sometimes even greater than the higher number given above. But even the slow rate of the elephant is sufficient, if the multiplication were unchecked, to enable the species to fill the world in a few years. The numerous offspring are always endeavoring to find room for themselves, and food to eat. For this purpose they distribute themselves as widely as possible.

3. *All organisms distribute themselves from the centers, where their reproduction is rapid.* All organisms, even those that seem stationary, have some method of dispersing themselves over the earth. The means of dispersal are chiefly the following: 1. By independent *migration.* This is true of almost all

animals, but it is not true of plants, which, as a rule, have no independent power of motion. 2. By *winds*. Many plants produce seeds or spores which can be blown for long distances by the wind, until they land in a favorable locality, where they can develop into new plants. This dispersal by the wind is not so common among animals, although some of the lighter animals which fly, like the insects and bats, may be blown for long distances by the wind. 3. By *water currents*. The ocean currents and fresh-water streams carry many animals and plants long distances. The Gulf Stream carries living organisms across the Atlantic Ocean, and a river flowing through a country may distribute seeds for hundreds, and even thousands, of miles. 4. *Incidental* means. There are various incidental methods by which seeds or eggs, or even living animals, may be distributed. Wood-boring insects may be carried on drifting logs; seeds may be carried in particles of mud clinging to the feet of flying birds; living animals may be carried for long distances on floating ice; ships carry living animals and plants all over the world; migrating animals not infrequently distribute seeds of plants as they move about from place to place, and they may even carry living eggs and some living animals in the same way.

By some of these means all organisms have an efficient method of distribution, and tend to scatter themselves in all directions from the centers, where they are produced in large numbers. Although the dispersal may be slow, in the end even the most slowly migrating animal or plant might be distributed over the face of the earth. All organisms tend to disperse themselves until further migration is checked. The factors which check their migration are spoken of as **barriers.**

Barriers.—*The ocean.*—Bodies of salt water are effectual barriers against the distribution of land animals. Flying animals cross small bodies of salt water, and animals and plants that are blown by winds may be distributed over the ocean

for considerable distances; but for most land animals the ocean is an effectual barrier.

The land.—For marine animals, the land proves to be an effective barrier. Although the conditions are essentially the same on both sides of the isthmus of Panama, the animals on the two sides of the isthmus are different, the narrow land barrier being sufficient to prevent animals from crossing from sea to sea. Land is also a fairly effectual barrier in preventing the water animals of one river system from passing to another. The inhabitants of the river may distribute themselves over a wide territory, but they are usually unable to pass from one watershed to another, except as they may be carried by incidental means.

Mountains.—The high mountain ranges are perhaps the most effectual barriers of all. Practically no animal or plant is able to cross over the higher mountain ranges. Hence it sometimes happens that the animals and plants upon the two slopes of high mountains may be quite different, even though the climatic conditions on the two sides are essentially the same.

Climate.—Each animal and plant is able to live only in certain conditions of climate. Hence the climate of a territory is a determining factor in regulating its inhabitants. In their distribution, animals and plants are frequently completely checked when they reach territories in which the climate is unadapted to them. This may be the result of several different factors.

1. Water.—The absence of water is a most effectual barrier to the distribution of either animals or plants. Deserts are uninhabited by any form of life, since no protoplasm can exist without water. Although most forms of life need a moist climate, some prefer one that is moderately dry and cannot live in moist territories. Deserts and semi-deserts will, therefore, be barriers for the greater number of animals and plants, while moist climates will be effectual barriers for the type of organism which prefers a semi-dry climate.

2. Food.—Animals and plants are limited to territories which furnish the food on which they subsist. A territory that fails to produce sufficient food for any given type of animal will prove an effectual barrier.

3. Temperature.—Forms of life adapted to a warm climate cannot live in a cold climate, and *vice versa.* The temperature of a territory is, therefore, a highly important factor in determining its inhabitants. Most animals living in cold regions will not pass over the equator, and those adapted to the warm equatorial climate cannot distribute themselves over the colder regions.

Enemies.—Every animal and plant has its special enemies. These enemies are sometimes in the form of parasites; they may be larger animals and plants, or other organisms that are contending for the same food. The mutual rivalries of organisms make one of the most complex problems of biology, and one that presents an endless puzzle. The introduction of any new animals into an old territory may produce unexpected changes in the life of the animals and plants, the newly arriving organisms seizing the available food, or destroying the life of other animals and plants, and giving rise to modifications in the fauna and flora, which can never be anticipated or predicted. The complexity of these relations is indicated in a famous example given by Darwin. The clover crop is dependent upon the bumblebees, which distribute its pollen and produce proper fertilization; the number of bumblebees is dependent upon the number of field mice who eat them; the field mice in turn are eaten by the cats; so that in this roundabout way the number of cats in a territory regulates the clover crop.

Change of type under new conditions.—The distribution of any particular species of animal or plant is modified by another factor of a different nature. When an animal migrates into a new territory, and comes under totally different conditions as to food, climate, and enemies, it is very apt to begin to change. These variations from the original type may, in the new terri-

tory, prove of special advantage rather than of disadvantage, and will be preserved, while the original type may be destroyed. In the new locality, the species often assumes a form quite unlike the original type, and becomes so differentiated that the descendants can hardly be recognized as belonging to the original species. This peculiar feature is especially noticeable on some of the oceanic islands. Such islands may be hundreds of miles from the mainland and only occasionally visited by accidental stragglers; but they develop peculiar types of animals and plants distinctly their own, although originally coming from the mainland. So different do they sometimes become that they can hardly be recognized as close allies of the mainland types. Although this change of type in new localities is especially noticeable on oceanic islands, it undoubtedly occurs on the continental areas as well. When a species migrates into a new territory, and is placed under new conditions of food and climate, and is in rivalry with new enemies, modifications of the original type are sure to develop, and in the end the form adopted is more or less different from that of the original immigrant, which may be limited to its original home.

DISTRIBUTION OF ORGANISMS IN TIME: PALEONTOLOGY

Geology discloses the fact that the earth's crust is made up of a series of rocks which have been deposited during the long ages of the past; and by the study of these successive layers of rock we can learn various facts concerning the history of the world during the time when the different strata were deposited. In many of these rocks we find remains of living organisms, called **fossils,** which comprised the life of the world at various periods in its earlier history. The study of these different fossil remains is known as **paleontology** (Gr. *palaios* = ancient + *on* = being + *logos* = speech), and gives us an outline history of organisms in the past.

Paleontological history at best is very incomplete, since it

is only under special conditions that the body of an animal or plant becomes imbedded in the rocks and preserved in the form of a fossil. Incomplete as it is, paleontology has shown us many illuminating facts concerning the earlier life of the world. It has shown that life has been in existence on the earth for many millions of years, although we have no means of determining, even approximately, how many. It has taught that during this long series of ages there has been a constant succession of living things, one type after another making its appearance and giving place to other types. The animals and plants living to-day represent only the last step in this long series, nearly all of the species existing at the present time being of recent origin, some having been in existence only a few thousands, or perhaps even a few hundreds of years, although some of our present forms may extend back for hundreds of thousands of years in the past. The immediate predecessors of our present species were organisms much like them, and from them the present forms have doubtless been descended; and preceding these were others, still more remote in time and more unlike the present ones in structure, representing still earlier ancestral forms.

The general history of any series of types has been approximately as follows: Appearing in a certain part of the world, a group of animals has dispersed itself more or less over the face of the earth, becoming numerous in species and giving rise to a variety of subordinate types. The development has commonly gone on until a climax has been reached, after which the particular type has perhaps remained constant for a time, but eventually declined toward its final extermination. As it disappeared, its place was taken by some other type, better adapted to the new conditions of the changing world. So the progress has gone on age after age, type after type appearing, developing, culminating, and then declining and disappearing.

One general law in this long progress is manifest. During the whole series of ages there has been a general progress of

type from lower to higher forms. The first organisms, appearing in the oldest rocks, were simple forms of low structure, while the highest forms of organisms appeared in the most recent ages. While the progress has not been uniformly constant, the general trend has always been upward. The invertebrates, which contain the lower animals, appeared and culminated first, while the vertebrates appeared later. Among the vertebrates the fishes appeared in the earlier rocks, the amphibia came next, reptiles and birds followed, and finally the highest group, the mammals, appeared last, with man at the extreme end of the series. It is true that in this long succession of ages, some forms of organisms have degenerated, becoming simpler and finally disappearing, while others have remained constant for immensely long periods of time without any apparent change. But the general tendency of the whole history has been one of progress from a low form to a higher, from the simple to the complex; and the living world to-day represents the culmination of a long period of progress from the earliest times. This progress, as disclosed by the fossils buried in rocks, is, in a very general way, parallel to the progress of the individual animal as it develops from the egg, through the series of changes which we have learned to call embryology. The parallel between embryology and paleontological history has been one of the striking discoveries of biological study, and has been one of the great factors in the disclosure of the unity of the living world during these long ages. All the facts to-day assure us that there have been uniform laws and forces extending through the whole series of living organisms, from the earliest geological ages to the present, and from *PROTOZOA* to *MAN*.

GLOSSARY-INDEX

In this index all defined words are printed in black-faced type; words to which only page reference is given are in roman type. In addition to the words used in the text, definitions are given for some of the more common biological terms. These may be recognized by their lack of page references.

alternation of generations, in animals, 277, in plants, 269, 273.

amitosis (Gr. *a* = without + *mitos* = thread).— Cell division without karyokinesis, 89.

Amœba, description of, 52.

amœboid (Gr. *amœba* + *-oid*).— Resembling *Amœba*, especially as regards movements by the protrusion of pseudopodia, 218.

amorphous (Gr. *a* = without + *morphé* = form). — Without regular shape.

amphiaster (Gr. *amphi* = around + *aster* = star).—The double star formed in karyokinesis, 86.

amphibious (Gr. *amphi* = around + *bios* = life).— Capable of living either in the air or in the water.

amphimixis (Gr. *amphi* = around + *mixis* = a mixing).— A name applied to the mixture of germ substance in sexual union, 336.

amylopsin.— A ferment found in the pancreatic juice, that converts starch into sugar, 306.

amylolytic.—Capable of converting starch into sugar.

anabolism.— The building up of chemical substances from simpler ones, 139, 225, 299.

anaërobic (Gr. *an* = without + aërobic).— Growing only in the absence of oxygen.

anæsthetics (Gr. *an* = not + *aisthesis* = feeling).— Drugs that destroy consciousness.

analogy (Gr. *ana* = according to + *logos* = a ratio).— Likeness in function, 368.

analysis (Gr. *ana* = up + *luein* = to loose).— The reduction of a compound to its component parts, 234.

anaphase.— The third stage of karyokinesis, 87.

anatomy (Gr. *ana* = up + *temnein* = to cut).— The study of the grosser structure of organisms, 19.

anchylosis (Gr. *angkylos* = crooked).— The growing together of bones.

animalculæ.— Microscopic organisms commonly found in water, 52.

animal functions.—Those distinctive of animals, *i. e.*, nervous and muscular, 217.

animals and plants, differences between, 217, 224.

annuals.— Plants which live a single season only.

Annulata (Gr. *anulus* = a ring).— A group of animals with the body divided into rings, 157, 378.

Anopheles, 71, 72.

antennæ.— Elongated appendages with sensory functions occurring on the head of certain animals.

anterior.— Pertaining to the head, 155.

anterior root.— The anterior branch of a spinal nerve, carrying impulses from the center, 194.

anther (Gr. *anthos* = a flower).— The sac on the end of a stamen bearing pollen, 119.

antheridia (Gr. *antheros* = flowery).— The organs in certain plants that produce the sperms, 271.

anthropoid (Gr. *anthropos* = man).— Resembling man.

anus.— The posterior opening of the digestive tract; the vent, 157.

aorta.— The large main artery which carries blood to the lower part of the body, 188.

aperture.— An opening.

apetalous (Gr. *a* = without + *petalon* = a leaf).— Flowers without petals, 119.

appendages.— Elongated projections from organisms, with special functions; like legs, tentacles, etc., 175.

appendix vermiformis.— A small, blind sac attached to the end of the large intestines.

Appert, 14.

aqueous humor.— The transparent liquid between the cornea and the lens of the eye, 197.

arachnoid membrane. — The membrane covering the brain, between the dura mater and the pia mater.

arborizations (Lat. *arbor* = a tree). — The fine branches in which many nerve fibers sometimes terminate, chiefly at their central ends, 170.

archegonia (Gr. *arché* = first + *gonos* = race). — The organs in certain plants that produce small eggs, 271.

arteries.— Blood vessels carrying blood from the heart, 190.

articular (Lat. *articulus* = a joint).— Pertaining to the joints, 177.

ascent of sap.— The flow of liquids from the roots to the leaves, 126.

Ascomycetes, 99.

ascospores.— Spores produced in asci, 79, 99.

ascus (Lat. *ascos* = a sac).— A sac holding a definite number of spores, 79, 99.

asexual reproduction, 238, 243, 262; distribution of, 265.

asexual stage (Gr. *a* = without + sexual).— The stage in a metamorphosis in which reproduction is by an asexual method.

Aspergillus, 97, 102.

asphyxia (Gr. *a* = without + *sphyzein* = to throb).— Suffocation.

assimilation (Lat. *assimulare* = to make like).— The power of converting nourishment into the substance of the body, possessed by all living things, 44, 62.

astragalus, 182.

atrophy (Gr. *a* = without + *trephein* = to nourish).— To decrease in size as the result of disuse, or from other causes.

auditory.— Pertaining to hearing, 194.

auricles (Lat. *auris* = ear).— The chambers in the heart that receive venous blood, 188.

automatic activity.— Actions started by the organisms and not brought about by any external stimulus: spontaneity, 3.

autophytes (Gr. *autos* = self + *phyton* = plant).— Plants which subsist upon minerals and gases, which they utilize through the agency of sunlight, 226.

available energy, 298.

avidity for water, 127.

axial.— Pertaining to the axis.

axial skeleton.— The skull and spinal column, with the ribs and sternum, 177.

axil.— The angle above the attachment of a leaf.

axis cylinder.— See *axon.*

axon.— The process from a neuron extending outward and becoming the axis cylinder of a nerve fiber, 170.

bacillus.— A motile, rod-shaped bacterium.

bacteria.— A group of extremely minute plants, the simplest and smallest known organisms, 26, 80, 232, 235.

ball-and-socket joints, 185.

barriers.— Factors that check the distribution of organisms, 380.

basioccipital, 180.

bast.— The fibers of the phloem.

bees, parthenogenesis in, 246.

bell animalcule.— Same as *Vorticella.*

biennials (Lat. *bi-* = twice + *annus* = year).— Plants that live two years, growing the first year and fruiting the second.

bilaterally symmetrical.— Having the two sides strictly counterparts of each other, 155.

bile.— The secretion of the liver; also called gall, 186.

biogenetic law (Gr. *bios* = life + *genesis* = creation).— The law that embryology tends to repeat past history, 290.

biological sciences, classification of, 18.

bladder, 199.

blade of leaf, 114.

blastula.— A hollow-sphere stage of the developing egg.

blend.— To mix, as when the offspring shows characters midway between those of its parents, 362.

blights, 232.

blood, 191.

blood vessels, 158.

body cavity.— The cavity between the intestine and the body wall; also called the **cœlom,** 157.

body wall.— The muscular walls which lie outside the body cavity; the outer wall of the body, 143, 157, 166.

bone, 27, 176.

brachial (Lat. *brachium* = the arm).— Pertaining to the arm, 190.

bract.— A leaf in the axil of which a flower is developed.

brain.— The enlarged front end of the nervous system in vertebrates, 192: sometimes applied to the cerebral ganglia of invertebrates, 162.

branchiæ.— Gills, 288.

branchial openings.— Openings in the neck, through which water may pass for respiration, 285.

bread raising, 80.

breeding season.— The season of the year during which reproduction occurs, 214.

bronchi.— The larger branches of the trachea leading to the lungs.

buccal.— Pertaining to the mouth, 185, 284.

budding.— Reproduction by the formation of buds which may become detached; gemmation, 78, 146, 239.

bulbus arteriosus.— The large arterial trunk arising from the ventricle of the frog, before it breaks up into branches, 188; also called *truncus arteriosus*.

bundle.— A cluster of elongated cells, 104.

butterfly, 72, 289.

calcaneum, 182.

calciferous (Lat. *calx* = lime + *ferre* = to bear).— Lime-producing, 169.

callosities (Lat. *callum* = a thick skin).— Thickenings of the skin.

calyx.— The outer row of leaves of a flower, usually green, 119.

cambium (Lat. *cambire* = to exchange).— The layer of active, growing cells inside the bark and outside the woody layers in exogenous plants, 105, 108.

cane sugar, 9.

capillaries (Lat. *capillus* = a hair).— The microscopic blood vessels between the ends of the arteries and the beginning of the veins, 190, 207.

capillarity, 127.

carbohydrates.— Starches, sugars, and celluloses, 9, 10.

Carchesium, 91.

cardiac (Gr. *cardia* = heart).— Pertaining to the heart.

carnivorous (Lat. *caro* (*carnis*) = flesh + *vorare* = to eat).— Feeding on flesh, 224.

carotids.— The two large arteries on the sides of the neck carrying blood to the head, 190.

carpals, 182.

carpels (Gr. *carpos* = fruit).— The separate parts (leaves) of which a pistil is composed, 120.

cartilage.— A hard material, softer than bone, which forms part of the skeleton, 27, 35.

cartilage bones.— Bones first formed as cartilage, 181.

casein.— A proteid present in milk and constituting the curd, 8.

castor bean, 103.

cat, 366.

caudal.— Pertaining to the tail.

cell.— One of the simple units of which living things are composed, 26, 37.

cell doctrine, 38.

cell sap.— A clear liquid inside of plant cells, 30.

cellulose.— A material related to starch and forming the cell wall of many plant cells; the basis of paper, cotton, etc., 35.

cell wall.— The covering on the outside of the cell, not present in all cells, 29, 34.

central nervous system, 162, 192.

centrosome (Gr. *centron* = center + *soma* = body).— A small body lying near the nucleus in animal cells and apparently the center of active forces, 29, 34.

centrosphere, 34.

centrum.— The large central disk of bone in a vertebra, 177.

cephalic (Gr. *kephale* = head).— Pertaining to the head.

cerebellum.— The larger of the two divisions of the hind-brain, 193.

cerebral ganglia.— The large ganglia in the head of an animal, usually two in number, 162.

cerebral hemispheres.— The anterior and largest part of the brain of vertebrates, 193.

cerebrospinal axis.— The central nervous system of vertebrates, composed of brain and spinal cord, 192.

chemical composition of living things, 5, 7, 42.

chemical compounds.— Substances made of two or more chemical elements joined in chemical union.

chemotropism (Eng. *chemesa* = chemical + Gr. *tropé* = a turning).— Reaction to chemical stimuli, 57.

chiasma.— The crossing of the optic nerves in the brain.

Chilomonas, 73.

chitin.— A horny material, like that of which insects' wings are made.

coagulate.— To change into a curd-like mass, 22.

coccus.— A spherical bacterium.

cocoon.— The stationary stage in the life of a butterfly, 72; the egg case of an earthworm, 165.

Cœlenterata (Gr. *koilos* = hollow + *enteron* = intestine).— Animals with only a single cavity and no body cavity, including *Hydra* and its allies, 377.

cœliac axis. — The arterial trunk from the dorsal aorta, supplying the viscera, 190.

cœlom (Gr. *koilos* = hollow).— Same as body cavity, 157.

Cœlomata (Gr. *koilos* = hollow). — Animals with a body cavity including all animals above Cœlenterata.

cœlomic fluid.— The fluid filling the body cavity, 158, 160.

cœnocyte (Gr. *koinos* = common + *cytos* = a cell).— A protoplasmic mass containing several nuclei, but without division into cells; same as syncytium.

cold-blooded.— A term applied to animals whose blood is of essentially the same temperature as the surrounding medium.

colloidal.— A term applied to substances which will not dialyze through membranes, 307.

colony.— A group of connected individuals, usually arising from one by asexual budding, 73, 92.

columella.— A rod connecting the tympanic membrane with the inner ear in the frog, 197.

commensalism (Lat. *cum* = together + *mensa* = table).— An association of two organisms in which neither is benefited nor injured, 230.

commissures (Lat. *committere* = to join).— Nerve cords connecting ganglia, 162.

communal.— Living in communities.

compound pistil.— A pistil made of several fused carpels, 120.

conductility.— The power possessed by protoplasm of transferring impulses from one end to the other, 43.

condyles.— The smooth protuberances by which the skull is attached to the first vertebra, 181.

conformity to type.— The appearance of like individuals in successive generations, 328.

congenital characters (Lat. *con* = with + *genitus* = born).— Characters that are fixed in the germ plasm, 327, 334.

conidia (Gr *conis* = dust).— Spores produced by constriction on the ends of threads rather than in a sporangium, 98.

conjugation (Lat. *com* = together + *jugare* = to join).— The union of two similar cells in reproduction, 65, 94, 247, 262.

connective tissue.— Material, usually fibrous, which connects the various parts of an animal.
consciousness, 5, 213.
conservation of energy, 294; applied to organisms, 303.
constructive processes, 139, 225, 299.
contagious.— Having the character of passing readily from person to person.
continuity of germ plasm, 329.
contractile vacuole, 55, 62.
contractility, 54.
convolutions.— Folds of the surface of the brain.
coördination (Lat. *con-* = with + *ordinare* = to arrange).— The orderly control of the various functions so that they act in harmony; the control of many muscles so that they act toward a definite end, 140, 162, 211; in plants, 137.
copulation.— The union of the sexes for the transferring of sperms to the eggs, 165, 215.
copulatory organs.— Organs used for bringing the sex cells together, 256.
coracoid, 182.
cork, 38.
cornea (Lat. *corneus* = horny).— The front, transparent covering of the eye, 196.
corolla.— The second row of leaves in a flower, usually colored, 119.
coronary arteries.— Arteries supplying the heart.
corpuscles.— Any small bodies, but chiefly applied to floating cells in the blood, 192, 205.
correlation of forces.— Same as transformation of energy.
cortex (Lat. *cortex* = bark).— The layers of cells inside the epidermis and outside the cambium of a young stem; the outer layers of any organ, as the cerebral cortex, 104, 112.
cotyledons.— The leaves of a plant in the seed, 123.
cranial nerves.— The nerves arising from the brain, 194.
cranium (Gr. *cranion* = skull).— That part of the skull that holds the brain, 180.
crop.— An expanded chamber of the digestive tract for storing hastily swallowed food, 158.
cross fertilization.— Fertilization of eggs from one individual, with sperms from another, 165, 267.
crus, 182.
cryptogams (Gr. *cryptos* = concealed + *gamos* = marriage).— Plants which do not produce flowers, 103.

crystalline.— Applied to substances that will dialyze through membranes, 307

crystalline lens.— The lens in the eyeball which focuses light on the retina, 197.

Culex, 72.

cutaneous (Lat. *cutis* = skin).— Pertaining to the skin, 191, 209.

cuticle (Lat. *cutis* = skin).— A thin, structureless membrane forming on the outside of the epidermis, 62, 166.

cyclical changes.— Changes which pass through a cycle but eventually return to the starting point, 5.

cyst.— A hard shell which is sometimes secreted around organisms in a dormant condition; any sac with a wall, developing abnormally in the body, 59, 74, 241.

cytoblastema, 38.

cytoplasm (Gr. *cytos* = cell + *plasma* = substance).— The liquid part of the protoplasm outside the nucleus, 32, 49.

dandelion, 370.

DARWIN, 352.

death, 3, 153.

decay.— Decomposition changes produced by bacteria in the presence of air; more complete than putrefaction, 81.

deciduous.— A term applied to plants that shed their leaves in the fall; also to mammals that shed the placenta at birth.

decomposition.— The chemical destruction of molecules. In biology the disintegration of organic substances, usually produced by bacteria or allied organisms.

degeneration, 233.

dehiscence (Lat. *dehiscere* = to open).— The opening of an organ to discharge its contents, 123.

dendrites (Gr. *dendron* = tree).— The branching processes arising from neurons, 170.

denitrification.—The reduction of nitrates to nitrites or simpler compounds.

dentine.— The inner, softer part of the teeth.

depressant.— Having the power of reducing activity.

dermis.— The inner layer of the skin, 176.

descent theory.— The theory that all organisms are genetically interconnected: evolution, 348.

dessication (Lat. *dessicare* = to dry up).— Drying, 57.

destructive processes, 139, 300.

deutoplasm (Gr. *deuteros* = second + *plasma* = substance).— The food yolk in the egg, 249.

DE VRIES, 357.

dextrose.— A form of sugar found in fruits; glucose, 9.
dialysis.— See *osmosis.*
diaphragm.—A muscular membrane separating the chest from the abdomen.
diastatic.— Capable of turning starch into sugar.
diastole (Gr. *diastole* = an expansion).— The period in each beat when the heart is relaxed, 188.
Diatoms, 136, 219.
dichotomous (Gr. *dicha* = in two + *temnein* = to cut).— Branching by regular division into pairs.
differentiate.— To become unlike; usually applied to parts originally similar but which acquire different structure and function, 95, 283.
digestion.— A series of changes in the chemical and physical nature of the food which renders it capable of absorption, 204, 305.
digestive cells, 145.
digestive juices.— The secretions which render the food capable of absorption, 55, 62, 204.
digits.— Fingers and toes.
digitigrade.— Walking on the tips of the fingers and toes.
dimorphism (Gr. *di-* = twice + *morphé* = form).—Showing two distinct forms.
diœcious (Gr. *di-* = twice + *oikos* = house).—Having the sexes in different plants.
diphtheria, 231, 232.
direct development.— Development without a metamorphosis, 290.
disease germs, 82.
disintegrate.— To break to pieces, 4.
dispersal.— The power of organisms to distribute themselves from centers, 379.
dissepiment.— See *septum.*
distal.— Farthest from the main body.
distribution, in space, 379; in time, 383.
divergence.— The appearance of two or more lines of descent from a common center, 337, 339.
diversities.— The slight differences found among individuals of the same species.
diverticulum.— Any sac-like outgrowth.
dogs, origin of, 339.
dominant characters (Lat. *dominari* = to rule).— Those which appear most prominently in the first generation after the crossing of races, 360.
dorsal.— Pertaining to the back, 155.
drones.— Male bees.
Drosera, 223.

ductless glands.— Gland-like structures without ducts, pouring their secretions into the blood.

ducts.— The large spiral or otherwise marked cells in the fibrovascular bundles; vessels, 106. In animals the tubes that carry the secretions of glands to the exterior, 105.

duodenum.— The first loop of the intestine below the stomach, 186.

dura mater (Lat. *durus* = hard + *mater* = mother).— A tough membrane on the outside of the brain, 194.

ears, 197.

earthworm, 155; physiology of, 216.

ecdysis.— The shedding of the skin.

ecology (Gr. *oikos* = house + *logos* = discourse).— The study of the mutual relations of animals to each other and to their environment, 20.

ectoderm (Gr. *ectos* = outside + *derma* = skin).— The outer layer of cells of animals, 141, 283.

ectoparasites.— Parasites living on the outer surface of their host, 230.

ectoplasm.— The outer layer of protoplasm in Protozoa, 54, 61.

efferent nerve fibers (Lat. *ex* = from + *ferre* = to bear).— Fibers carrying impulses away from the brain, 172, 212.

egg.— Same as *ovum*, 267.

egg sac, 163.

electropism (Gr. *electron* = amber + *tropé* = a turning).— The power of reacting to electricity, 58.

elements.— The ultimate varieties into which substances can be chemically analyzed, 5.

embryo (Gr. *embryon* = an embryo).— The young organism in the early stages of development, 19.

embryology.— The study of the development of the egg into an adult, 19; of the frog, 280.

embryo sac.— A name formerly given to the macrospore of a flowering plant, 122, 273.

emulsion.— Finely divided droplets of one liquid (usually oil) floating in another liquid, 23.

enamel.— The hard, outer covering of the teeth.

encyst.— To inclose in a cyst, 74, 241.

endoderm (Gr. *endon* = within + *derma* = skin).— The inner layer of cells of animals, lining the digestive tract, 143, 145, 283.

endodermis.— A layer of cells within the cortex and next to the wood in the roots of plants, 113.

endogenous stem (Gr. *endon* = within + *genes* = a producing).— Stems in which the fibrovascular bundles are irregularly arranged, with no cambium, wood ring, or bark, 112.

endoparasites.— Parasites living within the body of their host, 231.

endoplasm (Gr. *endon* = within + *plasma* = substance).— The inner layers of protoplasm in the Protozoan cell, 54, 62.

end organs.—Special organs at the ends of the nerves, 211; *peripheral* and *central* end organs are recognized.

enemies, relation of animals to, 382.

energy, 292; stored by plants, 299.

English sparrow, 345.

enteron.— The alimentary canal, 158.

entire.—Of a leaf margin, without indentations.

environment.— The surroundings which influence organisms, 351.

enzymes.— Substances secreted by organisms and having powers of fermentation; unorganized ferments, 306.

epiblast.— A name applied to the ectodermal layer of the embryo.

epidermis (Gr. *epi* = upon + *derma* = skin).— The outer layers of cells of any organism, 104, 115, 167, 176.

epiglottis (Gr. *epi* = upon + *glottis* = glottis).— An elastic lid covering the glottis, which prevents food from passing into the windpipe.

epiphysis.— Same as pineal gland, 193.

epithelio-muscle cells.— Cells of the ectoderm of *Hydra*, with contractile fibers extending from their base, 143.

epithelium (Gr. *epi* = upon + *thele* = nipple).— Cell layers covering surfaces or lining canals or cavities, 169.

equatorial plate.— The flattened mass of chromosomes formed between two centrosomes, 86.

erythrocytes (Gr. *erythros* = red + *cytos*).— The red corpuscles of the blood, 192, 205.

Eudorina, 263.

Euglena, 75, 76, 217.

Eustachian tubes.— The tubes leading from the throat to the middle ear, 186, 197.

eversion (Lat. *e* = out + *vertere* = to turn).— The process of turning a part inside out.

evolution.— The theory that traces the origin of the present world from the past as the result of the unfolding of natural law, 348.

excreta, 139.

excretions.— Waste products of metabolism eliminated by glands, 56, 139, 210.

excretory system.— 56, 62, 139; of earthworm, 161; of frog, 199; of *Hydra*, 151; of plants, 225.

exoccipital bones, 180.

exogenous stems (Gr. *exo* = without + *genes* = a producing).— Stems with a cambium layer separating a bark from a wood ring, 109, 112.

extensors.— The muscles that straighten the appendages at the joints, 211.

eye, 196; of human being and of frog compared, 367.

eyespot.—A colored spot found in unicellular organisms, sensitive to light, 76.

facial nerve. —The nerve supplying the side of the head with sensations, 194.

Fallopian tubes.— In mammals the part of the oviduct extending from the ovary to the uterus.

family.— A group of similar genera, 372.

fat.— One of the three chief food substances; a hydrocarbon made up of a fatty acid and glycerine, 9, 133.

fatty acid.— One of the materials into which fat may be decomposed, 10.

fauna.— The total animal life of any region.

Felis, 372.

females.— Individuals producing eggs, 251.

female pronucleus.— The matured egg nucleus before union with the sperm, 254.

female spores, 122.

ferment.— Chemical substances that produce fermentation; enzymes, 306.

fermentation, 79.

fern, life history of, 269.

fertilization.— The union of the egg nuclei and the sperm nuclei, 122, 249, 251, 257, 263. In botany the term is frequently erroneously applied to the transference of pollen to the pistil, 277.

fibers.— The individual elements of muscles and nerves, 170.

fibrillæ.— The minute filaments of which a muscle fiber is composed.

fibrin.— A proteid obtained from clotted blood.

fibrovascular bundles (Lat. *fibra* = fiber + E. vascular).— Bundles of long cells of various shapes, extending lengthwise and strengthening the stems of the higher plants, 104.

fibula, 182.

filament.— The thread-like stem to a stamen, 119; any thread-like organ.

fission (Lat. *findere* = to split).— Division into two equal halves, 58, 63.

flagella (Lat. *flagellum* = a whip).— Rather long, lashing processes of protoplasm, one to six to each cell, 73, 218.

flexors.— Muscles that bend the joints, 211.

flexure.— A bending.

Flora.— The total vegetation of any territory.

flowers, 118.

foam theory of protoplasm, 31.

fœtus.— The embryo while within the uterus of the mother, 291.

follicle.— The pocket in which a hair is produced.

foods of plants, 126.

food vacuoles.— Clear spaces in Protozoa representing the remains of digested food.

foramen magnum (Lat. *foramen* = opening + *magnum* = great).— The opening into the skull through which the spinal cord enters, 180.

forebrain.— The front part of the brain, consisting of cerebrum and thalamencephalon, 193.

fore-gut.— The front part of the alimentary canal; the *stomodæum.*

fossils.— The remains of animals or plants found in the rocks, 383.

fourth ventricle, 193.

free-living, 227.

frond.— The leaf of a fern, 269.

frontal bone, 180.

fundamental cells.— The cells which make up the bulk of the stem of young plants; they are roughly spherical in shape and never elongated, 104.

Fungi, significance in nature, 134, 234.

fusion nucleus.— The nucleus formed from the fusion of two nuclei into one, as in fertilization or conjugation, 65, 241, 257.

gall bladder.— The sac which temporarily stores the bile, 187.

gamete (Gr. *gameté* = husband or wife).— One of the uniting cells in sex union; usually male or female, but sometimes not showing any sex differentiation, 262, 267.

gametophyte (Gr. *gameté* = husband or wife + *phyton* = plant).— The stage in the life cycle of a plant that produces sex organs, 272, 275.

ganglion.— A group of aggregated neuron bodies, 162.

gastric glands, 204.

gastric juice.—The digestive secretion produced in the walls of the stomach, 204.

gastrovascular cavity.— The cavity in the body of Cœlenterata, 141.

gastrula (Gr. *gaster* = a stomach).— An early stage in the embryology of animals. See page 285.

gemmæ — Special buds formed for reproduction, gemmules, 243.

gemmation.— The same as budding, 239.

gemmules.— Special buds which break away from the parent and become new individuals; same as gemmæ.

generation.— The whole life history of an organism, from any stage to the same stage again, 67.

genital (Lat. *genere* = to produce).— Pertaining to reproduction.

genus (pl. *genera*).— A grouo of similar species, 371.

geotropism (Gr. *ge* = earth + *tropé* = a turning).— The power possessed by many plants of growing toward or away from the earth.

germinal.— Pertaining to reproduction.

germ layers.— The three layers formed in the developing embryo, 283.

germ plasm.— The substance which bears the hereditary traits and is continuous from generation to generation, 330.

gills.— Thin, expanded organs, bathed in water for respiratory purposes, 288.

gill slits.— See *branchial openings.*

girdling, 111, 129.

gizzard.— A muscular chamber of the digestive tract where food is ground, 158.

glands.— Groups of cells which produce secretions, 167, 176, 204.

glenoid cavity, 182.

glomerulus.— See *Malpighian body.*

glossopharyngeal (Gr. *glossa* = tongue + pharynx).— A nerve from the brain supplying the tongue and throat, 194.

glottis.— The opening of the trachea or larynx into the mouth, 186.

glucose.— A sugar from fruits, or artificially made from starch, containing maltose and dextrin, 9.

gluten.— A proteid from cereals, 8.

glycerine.— One of the decomposition products of fat, 10.

gonads.— Glands producing eggs or sperms, 251.

Gonium, 240.

grafting.— Inserting a part of one animal or plant into another in such a way that the inserted part retains its life and grows.

granular.— Filled with granules or minute solid particles.

granular theory of protoplasm, 31.

gregarious.— Congregating.

growth, 4.

guard cells, 116.

gullet.— The œsophagus, 158.

gustatory.— Pertaining to taste.

gynœcium.— Same as *pistil.*

hæmal (Gr. *haima* = blood).— Pertaining to the blood.

hæmoglobin (Gr. *haima* = blood + Lat. *globus* = globe).— A red proteid which colors the blood red, 158, 192, 209.

hair follicle.— The tiny pocket, within which each hair grows.

hairs, 35, 117.

hallux.— The great toe.

hand, 365.

hare, 345.

Haversian canals.— The canals in bone in which the blood vessels run.

heart, 187, 206, 309; of earthworm, 159.

heliotropism (Gr. *helios* = the sun + *tropé* = a turning).— The power possessed by plants of turning toward the sun.

helotism (Gr. *helot* = a slave).— An association of organisms in which one enslaves the other, 228.

hepatic (Gr. *hepar* = liver).— Pertaining to the liver.

hepatic vein.— The vein from the liver, 190.

herbivorous (Lat. *herba* = grass + *vorare* = to eat).— Feeding upon grass, herbs or other plants.

heredity.— The appearance in the offspring of characters of the parent, 326; nucleus in, 48, 259; Weismann's theory of, 329.

hermaphrodites.— Individuals possessing both male and female reproductive glands, 251.

heterocercal.— Applied to a tail-fin with one lobe longer than the other.

heterosporous (Gr. *heteros* = other + spore).— Producing more than one kind of spore; *i. e.*, macrospores and microspores, 274.

hibernation (Lat. *hibernare* = to winter).— The death-like sleep which some animals show in winter, 214.

high organisms.— Organisms with complex structure, 96.

hind-brain.— The posterior part of the brain, consisting of cerebellum and medulla, 193.

hind-gut.— The hind part of the intestine, the cloacal chamber; also called the *proctodæum*.

hinge joint, 185.

histology (Gr. *histos* = a web + *logos* = discourse).— The study of the microscopical anatomy of organisms, 19; of earthworm, 166.

holophyte (Gr. *holos* = whole + *phyton* = a plant).— Having the food habits of plants, *i. e.*, capable of utilizing sunlight and assimilating CO_2, 221.

holozoic (Gr. *holos* = whole + *zoon* = animal).— Having the food habits of animals, *i. e.*, nourished wholly on organic foods, 221.

homocercal.— Applied to a tail-fin with both lobes equal.

homologous (Gr. *homos* = like + *logos* = ratio).— Similar in structure, 364.

homosporous (Gr. *homos* = like + spore).— Producing only one kind of spore, 274.

Hooker, 38.

Horse, foot of, 365.

host.— A name applied to an animal or plant upon which another is living as a parasite, 227.

humerus, 182.

humor.— A name applied to the transparent liquids in the eye, 197.

HUXLEY, 40.

hybrids.— Organisms resulting from the crossing of different species, 268.

Hydatina, 57, 247.

Hydra, description of, 140.

hydrocarbons, 9.

hydroids.— Animals closely related to *Hydra*, 148, 277.

hydrophyte (Gr. *hydor* = water + *phyton* = plant).— Plants living in water or in a very wet habitat.

hyoid.— A V-shaped arch of bone under the jaw and surrounding the larynx, 181.

hyomandibular.— A chain of bones attaching the lower jaw to the skull in the frog.

hypha.— One of the filaments of a mycelium.

hypoblast.— Applied to the endodermal layer in the embryo.

hypophysis (Gr. *hypo* = under + *phuein* = nature).— See *pituitary body*, 193.

ileum.— A name given to the intestine below the duodeum.

ilium, 182.

imago.— The adult stage of an insect with a metamorphosis, 289.

imbibition (Lat. *imbibire* = to imbibe).— The action of absorbing water, shown by many organic substances.

immutability of species (Lat. *in* = not + *mutabilis* = changing).— The theory that species remain constant, 349.

imperfect flowers.— Flowers in which either stamens or pistils are lacking, 120, 121.

impregnation (Lat. *impregnare* = to make pregnant).— See *fertilization*, 257.

inbreeding.— Breeding from a male and female of the same parentage, like brother and sister, 268.

income, of an animal, 219; of a plant, 220.

incubation (Lat. *incubare* = to lie on).— To keep warm.

indirect development, 290.

individual, 67.

individual variations, 337, 358.

indusium (Lat. *induere* = to put on).— A covering over the sporangia in the sorus of a fern, 269.

inferior vena cava.— The large venous trunk bringing the blood from the lower parts of the body to the heart: same as *posterior vena cava*, 190.

infundibulum.— Any funnel-shaped or dilated organ, 193.

infusion.— A preparation made by steeping a substance like hay in warm water.

inner ear, 198.
inorganic, 26.
insertion.— The attachment of a muscle farthest from the center of the body, 184.
intercellular (Lat. *inter* = between + cellular).— Lying between the cells.
intercellular digestion, 145.
internodes.— Spaces between the nodes.
interstitial cells (Lat. *inter* = between + *sistere* = to set).— Cells in *Hydra* lying between the cnidoblasts and the muscle cells, 143.
intestine.— The digestive tract from stomach to cloacal chamber, 186.
intracellular (Lat. *intra* = within + cellular).— Lying within the cells.
intracellular digestion, 146.
intussusception (Lat. *intus* = inside + *suscipere* = to take up).— The process of growth by taking material inside the body and incorporating it into the body substance, 5.
invagination (Lat. *in* = within + *vagina* = a sheath).— The act of turning inward, as when the finger of a glove is pushed into the palm.
invertebrata.— A name given to all animals below vertebrata.
invertion.— The splitting of a molecule of cane sugar into two molecules of grape sugar, a molecule of water being added in the process, 9.
iris.— An opaque curtain, containing pigment, covering the front of the eyeball, 197.
irritability.— The power of reacting under the influence of stimuli, 43, 57, 63, 219.
ischia, 182.
isolation.— The separation of two individuals from the rest of the species so that they will breed together, 351.
jellyfish.— See *medusa*.
joints.— Places where bones or other hard movable parts come together, 176, 184.
karyokinesis (Gr. *karyon* = nucleus + *kinesis* = movement).— The process of cell division accompanied by a peculiar, complicated nuclear division; *mitosis*, 85.
karyoplasm (Gr. *karyon* = nucleus + *plasma* = substance).— The liquid protoplasm inside the nucleus; *nucleoplasm*, 32, 49.
katabolism, 139.
kidneys.— Glands in vertebrates secreting urea, 199.
kinetic energy (Gr. *kinetos* = moving).— Energy in motion; *active energy*, 293.
kingdoms.— The two divisions of organisms, animals and plants, 373.
lachrymal (Lat. *lachryma* = a tear).— Pertaining to tears.
lacteals.— Lymph vessels carrying absorbed fat from the intestine, 192.

lacunæ.— Spaces among the tissues in which lymph collects, 192, 208.

LAMARCK, 350.

Lamarckian factors. — Forces in evolution first suggested by Lamarck, 351.

lamella.— A thin plate or layer.

larva.—A free-living stage in the development of an animal, unlike the adult, *e. g.*, a tadpole, 286, 289.

larval history.— The stages in the life history of an animal after hatching from the egg and before adult form is reached.

larynx.— The enlargement of the air passages containing the vocal cords, 191, 209.

leaf, structure of, 114.

legumen.— A proteid derived from legumes, 8.

legumes.— Plants belonging to the Leguminosæ family, like beans, peas, clover, alfalfa, vetches, locusts, etc.

Leucanthemum, 345.

leucocytes (Gr. *leukos* = white + *cytos* = cell).— The white corpuscles of the blood, 192, 205.

lichens.— The grayish green mosses which grow on rocks or trees, etc.; an association of a fungus and a green plant, 229.

life cycle.— See *generation;* of nature, 234.

life force, 4, 323.

ligaments.— Bands of connective tissue connecting bones, 184.

lingual (Lat. *lingua* = tongue).— Pertaining to the tongue, 190.

linin.— The delicate fibers extending through the karyoplasm and forming a network, 32.

littoral.— Pertaining to the shore.

liver.— A large gland opening into the intestine at the pylorus, 186.

lophotrichic (Gr. *lophos* = a crest + *thrix* = hair).— With a tuft of flagella, 81.

low organisms.— Organisms with a simple structure, 96.

lumen.— A cavity in a tube or sac.

lungs, 191, 209.

lymph.— The liquid part of the blood after it has passed out of the capillaries into the tissues, 176, 192, 208.

lymph glands.— Glandular swellings on the lymph vessels, which belong to the ductless glands; *lymph nodes*, 192.

lymph hearts.— Four pulsating sacs in the frog, that force lymph into the veins, 192, 208.

lymph spaces.— Spaces in tissues in which lymph collects, 176.

lymph vessels.— Tubes carrying lymph from the lacunæ to the veins, 192, 208.

machine.— Any mechanism designed to convert one kind of energy into another, 297.

macronucleus (Gr. *macros* = large).— The larger of the two nuclei in cells having two, 62.

macrospore (Gr. *macros* = large).— The large spores in certain plants, which develop into female gametophytes, 122, 273.

macula lutea (Lat. *macula* = spot + *luteus* = yellow).— A small spot on the retina, with most acute vision.

malaria, 69, 232.

males.— Individuals producing sperms, 251, 257.

male pronucleus.— The sperm after entering the egg and before it unites with the egg nucleus, 257.

male spores, 122.

Malpighian bodies.— Minute rounded bodies in the kidneys filled with a knot of blood vessels; *glomeruli*.

Mammalia (Lat. *mamma* = breast).— Animals, the females of which have milk glands, 373.

mammary glands.— Glands secreting milk, 373.

mandible.— The jaw bone, 180; also the jaw-like teeth of animals like insects and crustacea.

mantle.— A fold of skin more or less enveloping the body of an animal.

marrow.— The soft material filling the cavities of bones.

maturation (Lat. *maturare* = to make ripe).— The final changes by which an egg becomes prepared for fertilization, 253.

maxilla.— A bone forming the upper jaw, 180; also mouthparts of insects or crustacea.

mechanical theory.— The theory that life phenomena are manifestations of chemical and mechanical forces only, 41.

medulla oblongata.— The posterior part of the brain, 193.

medullary rays (Lat. *medulla* = marrow).— Bundles of cells extending from the center to the outer parts of a stem, 111.

Medusæ.— The sexual, free-swimming stage of certain hydroids and other Cœlenterata; *jellyfishes*, 144, 278.

megaspore.— Same as *macrospore*.

membrane bones.— Bones formed first as membranes, 181.

membranella.— A band of fused cilia found in some of the unicellular animals, 61.

Mendelism.— A law of heredity first advanced by Mendel, 359.

mental functions, 317.

mesenteron (Gr. *mesos* = middle + *enteron* = intestine).—The mid-gut, 284.

mesentery (Gr. *mesos* = middle + *enteron* = intestine).— A fold of the peritoneum which slings the intestine in position, 187.

mesoblast.— The mesoderm of the developing embryo.

mesoderm (Gr. *mesos* = middle + *derma* = skin).— The middle layer in a developing embryo, 283.

mesoglœa (Gr. *mesos* = middle + *gloiòs* = glue).— The middle, non-cellular layer of *Hydra* and allied animals, 143.

mesophyll cells (Gr. *mesos* = middle + *phyllon* = leaf).— The irregular, loosely packed, chlorophyll cells in the middle of a leaf, 117.

mesophytes (Gr. *mesos* = middle + *phyton* = plant).— Plants living in a moderately moist habitat.

metabolism (Gr. *meta* = beyond + *ballein* = to throw).— A name given to the series of chemical changes going on in organisms, 138, 210.

metacarpals, 182.

metameres (Gr. *meta* = beyond + *meros* = a part).— Segments of animals like the earthworm, 155.

metamorphosis (Gr. *meta* = beyond + *morphé* = form).— A life history in which an organism passes through several unlike stages, more or less independent, 72, 289; of frog, 280, 286.

metaphase.— The second step in karyokinesis, 87.

Metaphyta (Gr. *meta* = beyond + *phyton* = plant).— Plants made of many cells, 223.

metastasis (Gr. *meta* = beyond + *histanai* = to place.)— The process of using foods, 132, 135, 300.

metatarsals, 182.

Metazoa (Gr. *meta* = beyond + *zoon* = animal).— Animals made of many cells, 223.

mice, breeding of, 361.

micronucleus (Gr. *mikros* = small + nucleus).— The small nucleus in a cell containing two nuclei, 62.

microörganism.— Any organism of microscopic size.

microsomata (Gr. *mikros* = small + *soma* = body).— Extremely minute bodies in the protoplasm which frequently show motion, 32.

microspores (Gr. *mikros* = small + spore).— The small spores in a plant, which develop into male gametophytes, 122, 273.

mid-brain.— The middle part of the brain, consisting of the optic lobes (called *corpora quadrigemina* in man), 193.

migration.— The act of changing one's dwelling place from one locality to another, 379.

mimicry.— Resemblances which some organisms show to other objects, for protective purposes.

mitosis (Gr. *mitos* = a thread).— See *karyokinesis*.

mitral valve.— The valve between the left auricle and ventricle.

molds, 96, 99, 235.

molecule.— The smallest particle of a chemical compound which can exist without the compound being chemically destroyed.

Monocystis, 241.

monœcious (Gr. *monos* = one + *oikos* = house).— With both sexes in the same individual; applied to plants, 251.

monogamous (Gr. *monos* = one + *gamos* = marriage).— The sexual association of one male with one female.

monotrichic (Gr. *monos* = one + *thrix* = hair).— With a single flagellum, 81.

morphology (Gr. *morphé* = form + *logos* = discourse).— The study of the structure of organisms in all relations, 19.

morula (Lat. *morum* = a mulberry).— The stage in the egg development after the egg has become a sphere of cells.

motion, in plants, 136, 218; in the earthworm, 167; in the frog, 211.

motor cells.— The neurons which send impulses over their axons to the muscles to produce motion, 172, 213.

motor ocularis.— The third cerebral nerve supplying the eye muscles, 194.

Mucor, 97, 247.

mucous membrane.— The lining of the alimentary canal, 187.

mucous.— Applied to glands secreting mucus.

mucus.— A thick, viscid secretion from the mucous membrane.

multicellular organisms (Lat. *multus* = many + cellular).— Organisms made of many cells which show a differentiation among themselves, 90, 95.

muscles, 219.

mutations (Lat. *mutare* = to change).— Sudden departures from the race character which have a tendency to remain fixed, 358.

mutation theory (Lat. *mutare* = to change).— The theory of evolution that assumes that progress has taken place by mutations rather than by individual diversities, 357.

mutualism.— An associating of organisms for mutual benefit, 228.

mycelium (Gr. *mykes* = fungus + *helos* = a nail).— The thread-like filaments of which fungi are composed, 96.

myosin (Gr. *mus* = muscle).— A proteid in lean meat, 8.

nares.— See *nostrils*.

nasal bones, 180.

natural selection. — The law by which the best fitted organisms survive, 353.

NEEDHAM, 13.

nematocysts (Gr. *nema* = a thread + *cystis* = sac).— Special cells in Cœlenterata which have a coiled poison thread capable of extrusion; *nettling cells*, 143.

nephridia (Gr. *nephros* = kidney).— The organs of the earthworm which excrete nitrogenous waste, 161.

nerve fibers.— The separate fibers of which a nerve is composed, 170.

nerve impulse, 314.

nerves, 163, 194.

nervous system of earthworm, 162; of frog, 192; of *Hydra*, 146.

netted-veined leaves.— Those with veins branching into a network, 114.

nettle-hairs, 117.

nettling cells.— See *nematocysts*.

neural arch (Gr. *neuron* = a nerve).— The arch of bones on top of the vertebræ, inclosing the neural foramen, 177.

neuroglia (Gr. *neuron* = a nerve + *gloios* = glue).— The connective framework of the nervous system.

neurons (Gr. *neuron* = a nerve).— The nerve cells which are the units of the nervous system, 169, 195.

nictitating membrane (Lat. *nictare* = to wink).— A semitransparent, inner eyelid in the frog and some other animals, 175.

nidamental glands (Lat. *nidus* = a nest).— Glands connected with the oviduct, that secrete the covering of eggs, 201.

Nitella, 29.

nitrification.— The production of nitrates in the soil from simpler nitrogen compounds.

nodes.— The places on a stem where branches arise.

nostrils.— Openings into the nasal cavities; *nares*, 175, 186.

notochord (Gr. *notos* = the back + *chordé* = a string).— A rod in the back of vertebrate embryos that develops into the spinal column, 286.

nucleolus.— A small body in the nucleus of a cell, with unknown functions, 32.

nucleoplasm.— See *karyoplasm*.

nucleus.— The vital center of a cell, containing chromatin and controlling constructive metabolism, 29, 32, 45.

occipital bones.— The skull bones which surround the foramen magnum, 180.

occipital condyles.— The rounded protuberances by which the skull articulates with the first vertebra, 181.

œsophagus.— The tube from the throat to the stomach or crop, or from the mouth into the body, 60, 158.

olfactory lobes.—Two small lobes of the brain in front of the cerebrum, 193.

olfactory nerve.— The first of the cerebral nerves, supplying the olfactory sacs, 194, 196, 198.

olfactory sacs.— Minute sacs in the nasal cavities; the seat of the sense of smell, 196, 198.

omosternum (Gr. *omos* = shoulder + *sternon* = the chest).— A bit of cartilage forming the front of the sternum in the frog, 182.

ontogeny (Gr. *ont* = being + *-geneia* = a producing).— Development from the egg, 19, 290.

oöcyte (Gr. *oön* = egg + *cytos*).— An egg before maturation, 252.

oögenesis (Gr. *oön* = an egg + *genesis* = creation).— The development of the egg in the ovary, 252.

oögonium (Gr. *oön* = an egg + *gonos* = offspring).— A sac in some plants within which are produced one or two eggs.

operculum.— A lid-like cover.

optic lobes.— The section of the brain in front of the cerebellum; the mid-brain, 193.

optic nerve.— The second cerebral nerve, supplying the eye, 194, 196.

optimum temperature, 132.

oral.— Pertaining to the mouth, 60.

order.— A group of similar families, 372.

organ.— Any part of an animal or plant adapted for a specific function; usually made of a combination of several different tissues, 26, 95.

organic evolution, 349.

organic substances.— Substances originally derived from organisms, 26; in chemistry, any compounds of carbon.

organism.— A living being provided with organs; hence any living being, 26.

organisms as machines, 298.

origin.— The attachment of a muscle nearest the center of the body, 184.

Oscillaria, 136, 219.

osmosis.— The force that causes some substances to diffuse through membranes which are moistened on both sides; *dialysis*, 127, 307.

ossification.— Turning to bone.

osteoblast (Gr. *osteon* = a bone + *blastos* = a sprout).— A bone-forming cell.

otic.— Pertaining to the ear, 180.

otocyst (Gr. *ous* = the ear + *cystis* = a sac).— A sac which in many invertebrates is supposed to have hearing functions.

otoliths (Gr. *ous* = the ear + *lithos* = a stone).— Calcareous bodies found in the otocysts in some animals.

outgo, of an animal, 220; of a plant, 220.

ova.— The female reproductive cells, 249, 267.

ovary.— In animals the glands producing eggs, 151, 163, 200, 249; in flowers the lower part of the pistil containing the ovules and seeds, 120.

overproduction, 353.

oviducts.— Ducts for carrying eggs to the exterior, 163, 200, 249.

oviparous animals.— Animals that lay eggs, 290.

ovules.— The small bodies in the pistil that contain the macrospores and grow into the seed, 121.

oxidation.— Union with oxygen, as in ordinary combustion, 55, 138.

palatine bones, 180.

paleontology (Gr. *palaios* = ancient + *ont* = being + *logos*).— The study of the distribution of organisms in the past ages by means of fossils, 383.

palisade cells.— A layer of regular, chlorophyll cells, just beneath the upper epidermis in most leaves, 117.

pallium.— See *mantle*.

pancreas.— A digestive gland opening into the intestine just below the stomach, 187, 204.

pancreatic fluid or juice.— The secretion of the pancreas, 204, 306.

Pandorina, 73, 90, 263.

papilla.— A small finger-like projection.

parallel-veined leaves.— Those with veins running from base to tip, or from midrib to margin, in a roughly parallel course, 114.

Paramecium, description of, 59.

parasite.— An organism that lives upon and feeds upon a living host, 227.

parasitism, effect of, 231.

parasphenoid bones, 180.

parenchyma (Gr. *para* = beside + *enchein* = to pour in).—Short, square-ended cells in plants, 106.

parietal bones, 180.

parotids.— Salivary glands in front of the ear in some animals.

parthenogenesis (Gr. *parthenos* = virgin + *genesis* = a creation).— Reproduction by eggs which do not require fertilization, 246, 262, 265.

PASTEUR, 14.

PASTEUR's solution, 83.

patheticus. — The fourth cerebral nerve, supplying the eye muscles, 194.

pathogenic (Gr. *pathos* = disease + *-genic*).— Disease producing, 82.

pectoral.— Pertaining to the chest.

pedal (Gr. *pous* = a foot).— Pertaining to the feet.

peduncle.— The stalk supporting a flower, 118.

pelagic (Lat. *pelagus* = the sea).— Pertaining to the open ocean.

pelvis.— The girdle of bones attaching the legs to the spinal column, 182.

Penicillium, 96.

penis.— The male copulatory organ, 291.

pepsin.— A ferment in the gastric juice.

peptone.— A soluble form of proteid.

peptonize.— To convert ordinary proteids into peptones.

Peranema, 75, 217.
perennials (Lat. *per* = through + *annus* = year).— Plants living year after year.
perfect flowers.— Those with both stamens and pistils, 121.
perianth (Gr. *peri* = around + *anthos* = a flower).— A name given to the calyx and corolla combined, 119.
pericardium (Gr. *peri* = around + *cardia* = the heart).— A sac surrounding the heart, 187.
perichondrium (Gr. *peri* = around + *chondros* = cartilage).— Fibrous material surrounding cartilage.
peripheral system, 163.
periosteum (Gr. *peri* = around + *osteon* = bone).— Fibrous material surrounding bone.
peristalsis (Gr. *peri* = around + *stellein* = to place).— The writhing motions of the intestine, 205.
peritoneum (Gr. *peri* = around + *teinein* = to stretch).— The membrane lining the abdominal cavity, 167, 171, 187.
peritrichic (Gr. *peri* = around + *thrix* = hair).— With flagella distributed over the body, 81.
perivisceral fluid (Gr. *peri* = around + Lat. *viscera*).— See *cœlomic fluid.*
pes.— The foot.
petals.— Leaves which form the corolla, 119.
petiole.— The stem of a leaf, 114.
phagocytes (Gr. *phagein* = to eat + *cytos* = a sac).— Leucocytes with the power of absorbing solid objects, 205.
phalanges.— The bones of the fingers and toes, 182.
phanerogams (Gr. *phaneros* = visible + *gamos* = marriage).— Plants which produce flowers, 103.
pharynx.— The throat cavity, 158.
phloem (Gr. *phloios* = inner bark).— The bark, 105.
photosynthesis (Gr. *phos* = light + *synthesis* = composition).— The function of starch making, possessed by green plants only, 129, 135, 218.
phototropism (Gr. *phos* = light + *tropé* = a turning).— Reaction to light, 58.
phyla.— The largest subdivisions of animals and plants, 373.
phylogeny (Gr. *phylon* = tribe + *-geneia* = a producing).—The past history of organisms, 290.
physiology (Gr. *physis* = nature + *-logia*).— The study of the functions of the different animals and plants, 19.
pia mater (Lat. *pius* = delicate + *mater* = mother).— A delicate membrane surrounding the brain and cord, inside the dura mater, 194.
pigeons, 338.

pigment cells (Lat. *pingere* = to paint).— Cells which contain coloring matter, 176.

pineal gland.— A small body lying on top of the brain; also called the pineal eye; same as *epiphysis*, 193.

pistil.— The central row of leaves (carpels) of a flower, bearing female reproductive organs; also called the *gynœcium*, 120.

pith.— The central mass of cells in a stem, made of fundamental cells, 104.

pituitary body.— A small body on the under side of the brain; the *hypophysis*, 193.

placenta.— The membrane by which the embryo is attached to the uterus in mammals, 291; in plants, the line of attachment of seeds in the ovary.

plankton (Gr. *plankton* = wandering).— The living organisms which float in water, largely microscopic.

plantigrade.— Walking on the palms of the hands or the soles of the feet.

plasma.— The liquid portion of circulating blood, 191, 205.

plasmodium (Gr. *plasma* = substance).— A jelly-like mass.

Plasmodium malariæ, 69, 239.

plastids.— Miscellaneous bodies within a cell, 37.

platelets.— Minute bodies in the blood of vertebrates, 192.

pleura (Gr. *pleura* = a rib).— Membranes surrounding the lungs.

Pleurococcus, 77, 239.

plexus (Lat. *plectare* = to weave).— A network of nerves, 194.

pneumogastric (Gr. *pneumon* = lung + *gaster* = stomach).— A large, cerebral nerve extending down the neck and supplying the heart, lungs, and stomach, 194.

Podocoryne, 277.

poisons.— Substances which, taken into the body, produce injurious effects, 43.

polar cells.— Small cells extruded from the egg during its maturation, 254.

pollen.— The male spores produced by a flower, 119.

pollen tube.— An outgrowth from a pollen grain which pushes through the style of a flower to fertilize the egg in the ovary, 122, 275.

pollex.— The thumb.

pollination.— The transfer of the pollen to the stigma, 277.

polygamous (Gr. *polus* = many + *gamos* = marriage).— The sexual association of one male with several females.

polymorphism (Gr. *polus* = many + *morphé* = form).— The property of having two or more forms of the same animal, 149.

portal circulation.— The circulation of blood from the intestine through the liver; it has two capillary systems, 190.

portal vein.— The vein carrying blood from the intestine to the liver, 190.

posterior end, 155.
posterior root.— The branch of the spinal nerve entering on its posterior side and carrying impulses toward the brain, 195.
posterior vena cava.— Same as *inferior vena cava*, 190.
potential energy, 293.
precoracoid, 182.
predatory.— Living by preying upon other animals.
premaxillary bones, 180.
proboscis.— An elongated portion of the head of an animal, with special functions.
process.— Any small projection.
procœlous (Gr. *pro* = before + *coilos* = hollow).— Applied to vertebræ which are concave in front only.
proctodæum, 284.
pronation.— The position of the fore arm with the palm downward.
pronuclei.— The two nuclei, male and female, which are in the matured egg, ready to unite with each other, 254, 257.
prophase.— The preliminary stage in karyokinesis, 85.
prostomium (Gr. *pro* = before + *stoma* = mouth).— The sensitive lobe projecting over the mouth in the earthworm, 156.
protective resemblances.— Resemblances to objects, either animate or inanimate, for the purpose of protection; *mimicry.*
proteids.— Highly complex compounds of carbon, oxygen, hydrogen, and nitrogen and some other elements; the basis of living tissues and a necessary part of animal foods, 7, 133.
prothallium (Gr. *pro* = before + *thallos* = a branch).— The small, sexual stage of the life history of a fern, 271.
protomitomic theory, 50.
Protophyta (Gr. *protos* = first + *phyton* = plant).— The unicellular plants, 222.
protoplasm (Gr. *protos* = first + *plasma* = substance).— The living substance of organisms, 29, 30, 40, 48.
Protozoa (Gr. *protos* = first + *zoon* = animal).— The unicellular animals, 92, 222.
proximal.— Nearest to the body.
pseudonavicellæ (Gr. *pseudes* = false + Lat. *navicella* = a boat).— Spindle-shaped spores formed by some *Sporozoa* as the result of the union of cells.
pseudopodia (Gr. *pseudes* = false + *pous* = foot).— Temporary lobes of protoplasm used in locomotion, 52.
psychology (Gr. *psyché* = the soul + *-logia*).— The study of mind, 20.
pterygoid bones, 180.

ptyalin.— The enzyme in saliva which converts starch into sugar.

pubis, 182.

puffballs, 245.

pulmonary arteries (Gr. *pleumon* = a lung).— Blood vessels carrying blood to the lungs, 191.

pulmonary circulation.— The circulation through the lungs, 191.

pulmonary veins.— The blood vessels carrying blood from the lungs to the heart, 191.

pupa.— A stationary, inactive stage between a larva and an adult, 289.

pupil.— An opening in the center of the iris allowing light to enter the eye, 197.

putrefaction.— Decomposition of organic products, taking place without the presence of much oxygen, 81.

pylorus.— The opening of the stomach into the intestine, 186.

quadrate bones, 180.

quadrato-jugal bones, 181.

rabbit, skeleton of, 364.

race variations.— Variations by which the race is gradually or suddenly modified, 338.

racemose.— Arranged somewhat like a cluster of grapes.

radiant heat.— Heat which is given off from a hot body into space, 297.

radius, 182.

ramus.— A branch.

reaction.—A response to an external stimulus, 43.

recapitulation theory.— See *repetition.*

receptacle.— In botany, the end of the flower peduncle on which the floral leaves are borne, 118.

recessive characters (Lat. *recessus* = receding).— Characters which fail to appear in a first generation, but may appear in later generations, 360.

rectum.— The enlarged, posterior end of the intestine, 186.

REDI, 12.

reflex action.— An action produced by a stimulus passing to the central nervous system and there giving rise to stimuli which pass outward to the muscles, but without volition, 212.

regeneration.— The redevelopment of parts that have been lost, 150.

reintegrate.— To recombine compounds that have been disintegrated.

renal.— Pertaining to the kidneys.

renal portal vein.— A vein from the legs of the frog that breaks up into capillaries in the kidney, 191.

repetition, law of.— The law that the development of animals repeats their past history, 290.

sclerotic coat (Gr. *scleros* = hard).— The outer covering of the eyeball, 196.

sea nettles.— See *jellyfishes*.

sebaceous glands (Lat. *sebum* = fat).— Oil glands in the skin.

secreting cells.— Cells which extract material from the blood and secrete special substances, 145, 161.

secretions.— Materials eliminated by the glands and used by the body for some special purpose, *e. g.*, gastric juice.

seed.— A young plant surrounded by a shell and lying dormant; developed in higher plants only, for the purpose of distribution, 122.

seedling.— The young plant in a seed, or just sprouting from a seed, 123.

segmentation.— A term describing the division of the earthworm into segments, 155; the division of the egg into many cells in development (*cleavage*), 280.

segment.— The name applied to the rings of which a body like the earthworm is composed; *metameres*, 155.

segregation (Lat. *segregare* = to separate).— The grouping together of individuals which show resemblances.

semicircular canals.— Canals in the inner ear, associated with the sense of equilibrium, 198.

semilunar valves.— Valves at the beginning of the pulmonary arteries and the aorta, 310.

seminal receptacles.— Sacs of the earthworm for holding the sperms received at copulation, 165.

seminal vesicles.— Sacs in the earthworm for holding sperms before they are ejected during copulation, 164, 200.

sensation.— A conscious feeling, produced in the brain as the result of impulses reaching it from the various sense organs, 212, 316.

sensations in plants, 137.

sense organs.— Organs at the outer ends of the nerves which are excited by external stimulation, 167, 172, 195, 212.

sensitiveness.— Same as *irritability*, 219.

sensitive plants.— Plants which respond quickly to touch by closing their leaves, 137.

sepals.— The leaves which form the calyx, 119.

septa.— Partitions separating chambers, especially in the earthworm, 157.

serous.— Applied to glands secreting a thin, watery liquid.

serous membranes.— Membranes lining the body cavity and thorax.

serum.— The liquid part of the blood after the clot has separated.

setæ.— Minute bristles serving to aid the earthworm in locomotion, 167.

sexual reproduction.— Reproduction by union of eggs and sperms, 71, 238, 240, 262; distribution of, 266. In earthworm, 163; in frog, 214; in *Hydra*, 151; in plants; origin of, 263; purpose of, 335.

sexual stage.— The stage in a metamorphosis in which sexual organs are produced.

shell, of an egg, 250.

shoulder girdle, 181.

sieve cells.— Large vessels in plants, with perforated partitions separating them from each other, 106.

sinus.— Any irregular space or dilated blood vessel.

skeleton, 139, 176.

skin, 35, 176.

skull, 180.

sleep of plants, 137.

smell.— See *olfactory organs.*

sociology (Lat. *socius* = a companion + Gr. *-logia*).— The study of the relations of organisms in forming societies, 20.

somaplasm (Gr. *soma* = body + *plasma* = substance).— The bit of the germ substance in the egg that is set aside in the developing egg to give rise to the new individual, 332.

somatic (Gr. *soma* = body).— Pertaining to the body.

sorus (plural, **sori**).— A cluster of sporangia in the leaf of a fern, 269.

Spalanzani, 13.

special creation theory, 350.

specialization.— Adaptation to some special function.

species.— The name given to a group of organisms essentially alike, 370.

sperms.— The male cells in sexual reproduction, 250, 255, 267.

spermaphytes.— Seed-bearing plants, *phanerogams*, 376.

spermaries.— The glands that produce the sperms, 164, 199, 250.

spermatocyte (Gr. *sperma* = seed + *cytos* = cell).— A cell in the spermary that is to break up to form sperms, 254.

spermatogenesis (Gr. *sperma* = seed + *genesis* = creation).— The development of the sperms, 254.

spermatozoids.— A name sometimes given to the motile sperm-cells of plants, 271.

spinal cord.— The part of the central nervous system of vertebrates extending through the spinal column, 193.

spinal nerves, 194.

spindle, 86.

spiracles.— Openings of gill chambers, as in tadpoles; also breathing pores of insects.

spiral cells.— Cells of a fibrovascular bundle with their inner wall thickened to form a spiral thread, 106.

spireme (Gr. *spirema* = a coil).— A name applied to the chromatin when it forms a thread, prior to division, 85.

Spirogyra, 30.

splanchnic.— Pertaining to the viscera.

spleen.— A good-sized organ lying among the folds of the intestine, 187.

spontaneity.— Power of producing movements from internal causes, 2.

spontaneous generation.— The theory that life can arise in some other way than from previously existing life; abiogenesis, 10.

sporangium (Gr. *spora* = a seed + *angeion* = a receptacle).— A sac within which spores are produced, 100, 270.

spores (Gr. *spora* = a seed).— Single-celled reproductive bodies, capable of growing into a new plant without fertilization, 16, 59, 79, 81, 239, 267.

sporoblast (Gr. *spora* = seed + *blastos* = a germ). — A sac in which sporozoites are produced, 242.

sporophyte (Gr. *spora* = seed + *phyton* = a plant).— The stage, in a plant with alternation of generations, that produces spores, 272, 274.

Sporozoa, 241.

sporozoites (Gr. *spora* = seed + *zoon* = animal).— Spores that result from the division of fused gametes, 241.

squamosal bone, 180.

stamens.— The modified leaves of a flower that produce pollen, 119.

starch.— A carbohydrate with the general formula $C_6H_{10}O_5$, or some multiple of this, 8, 129, 134.

stereome cells (Gr. *stereos* = a solid).— Cells in the bark with very thick walls, 106.

stereotropism (Gr. *stereos* = a solid + *tropé* = a turning).— Reaction to solid objects, 53.

sterility.— Unfertility, or inability to produce offspring, or hybrids, 268.

sterilize.— To treat an object so as to destroy all living things in it, 14, 17.

sternum, 182.

stigma.— The roughened surface on the end of a style, for the reception of pollen, 120.

stimulus.— Any force applied to an organism which will produce a reaction, 43.

stinging cells, 143.

stipules, 114.

stomach, 186.

stomata (Gr. *stoma* = mouth).— Openings through the epidermis of plants through which gas enters and moisture evaporates, 116.

stomodæum, 284.

strawberry plant, reproduction of, 244.

streaming of protoplasm.— The circulating motion of protoplasm within a cell, 32.

struggle for existence, 353.

style.— The projection on top of an ovary in a flower, 120.

subspecies.— A subdivision of a species; sometimes called a variety, 371.

sugar.— A carbohydrate with the general formula $C_6H_{12}O_6$ (monosaccharide) or $C_{12}H_{22}O_{11}$ (disaccharide), 8, 132, 134.

summer eggs.— Eggs produced in the summer which develop at once, 247.

sundew, 224.

sunlight, 131.

supination.— Position of the forearm when the palm of the hand is uppermost.

support, 139.

supraoccipital bones, 180.

survival of the fittest.— Same as *natural selection*, 353.

suspensorium, 180.

suture.— A jagged union between two bones, as in the skull.

swarm spores.— Spores with flagella enabling them to swim; zoöspores. 74.

symbiosis (Gr. *sun* = together + *bios* = life).— The living together of two organisms in close relations, which may be advantageous or disadvantageous to each, 228.

sympathetic system.— Two chains of nerve ganglia and nerves lying in the body cavity, parallel to the spinal cord, 195.

symphysis.— A union of two bones in the median line of the body.

syncytium (Gr. *sun* = together + *cytos* = cell).— A mass of living protoplasm with many nuclei but no cell boundaries; acellular, 89, 99.

synovial glands.— Glands which secrete lubricating fluid into joints, 184.

synthesis (Gr. *sun* = together + *tithenai* = to place).— The building of a compound out of simpler parts, 234.

systematic zoölogy.— The study of organisms which gives attention to classification and naming of species.

systemic circulation.— That part of the circulation which includes the vessels that supply all the body except the lungs, 191.

systole (Gr. *systole* = contraction).—The period of contraction of the heart, 188.

tactile.— Pertaining to touch.

tadpole, 288.

tarsals, 182.

taste, 198.

taxonomy (Gr. *taxis* = arrangement + *nemein* = to arrange).— The study of the classification of organisms, 19.

telophase.— The last stage of karyokinesis, 87.

tendons.— Bands of connective tissue binding muscles to bones, 185.

tentacles.— Appendages from an animal, usually motile, and serving as sensory and prehensile organs, 141.

testis.— See *spermary*.

thalamencephalon.— The small section of the brain behind the cerebrum, with the pineal gland on top of it, 193.

thallophyte (Gr. *thallos* = a shoot + *phyton* = a plant).— A plant that does not show differentiation into root, stem, and leaf, 375.

thallus (Gr. *thallos* = a shoot).— A flat leaf or branch.

thermotropism (Gr. *thermos* = heat + *tropé* = a turning).— Reaction to temperature, 57.

thigmotropism (Gr. *thigma* = touch + *tropé* = a turning).— Reaction to mechanical stimulation, 57.

thoracic duct.— The large lymph duct in mammals, carrying lymph from the lower parts of the body to the veins in the neck, 209.

thymus.— A ductless gland in the neck, especially prominent in the young.

thyroid gland.— A ductless gland in the neck below the larynx.

tibia, 182.

tissue (Lat. *texere* = to weave).— A collection of similar cells in a multicellular animal, 27, 95.

tongue, 185.

tonsils.— Two ductless glands in the back part of the mouth.

touch, 198.

touch corpuscles.— End organs of touch.

trachea (Gr. *trachea* = windpipe).— The air passage from the lungs; the *windpipe*, 209.

tracheids.— The thick-walled wood cells with tapering ends, found in fibrovascular bundles, 105.

transformation of energy, 296.

transpiration.— The evaporation of water through the leaves.

transverse processes (Lat. *trans* = across + *vertere* = to turn).— Lateral projections from the vertebræ, 177.

Trichina, 231.

trichocysts, 61.

tricuspid valve.— The valve between the right auricle and ventricle.

trigeminal.— The fifth cerebral nerve, supplying the sides of the head with sensations, 194.

trypsin.— A ferment found in pancreatic juice, digesting proteids.

tubercles.— Knob-like growths, usually indications of disease.

tuberculosis, 231, 232.

turgor.— The pressure of liquids within the cells of plants.

veins.— Blood vessels carrying blood to the heart, 190; the fibrovascular bundles in a leaf, 114.

vent.— See *anus*.

ventral side, 155.

ventral cord.— The nerve cord on the ventral side of the body cavity of the earthworm and some other animals, 163, 171.

ventricle (Lat. *venter* = stomach).— The lower chamber of the heart that forces blood into the arteries, 188.

venus sinus.— A large blood vessel on the dorsal side of the heart of a frog into which the venus blood collects before passing into the right auricle, 188.

vertebræ.— The separate bones of the backbone or spinal column, 177.

Vertebrata.— Animals which possess a backbone or its equivalent, 176, 373.

vesicle.— A sac.

vessel (Lat. *vasa* = a vessel).— Any hollow tube or cavity, 105.

vestigial organs.— Functionless remains of organs, formerly larger and functional.

villi.— Projections on the inside of the intestine which serve to absorb food, 308.

viola, 372.

viscera.— The organs of the abdominal cavity, 175.

vital energy, or vitality, 41, 309, 319.

vitalistic theories.— The theories that regard life as a distinct force, 323.

vitelline membrane (Lat. *vitellus* = yolk).— A cell wall of an ovum, 249.

vitreous humor (Lat. *vitrum* = glass).— The transparent liquid back of the lens and filling the eyeball, 197.

viviparous.— Producing young alive, 290.

vocal cords.— The membranes in the larynx whose vibration produces the voice, 209.

vomers, 180.

VON MOHL, 40.

Vorticella, 91.

warm-blooded.— With blood that always maintains an equable temperature.

WEISMANN, 328, 355.

wilts, 232.

winter eggs.— Eggs of certain animals, designed to live over winter, usually requiring fertilization, in distinction from summer eggs which do not, 247.

Wolffian body.— The primitive kidney found in the vertebrate embryo.

wood.— Same as *xylem*.

worker bees.— Female bees whose sexual organs do not mature, and who perform the work of the colony.

xerophytes (Gr. *xeros* = dry + *phyton* = a plant).— Plants inhabiting very dry regions.

xylem (Gr. *xylon* = wood).— The layers of hard woody cells inside the cambium layer in exogenous stems; the *wood*, 105.

yeast, 78, 235.

yolk.— The food material deposited in an egg for the nourishment of the developing embryo, 250.

zooid (Gr. *zoon* = an animal).— A more or less independent member of a compound organism, like a hydroid, 148.

zoöspore (Gr. *zoon* = an animal + *spora*).— Spores which swim by the agency of motile flagella or cilia, 93, 136.

Zoöthamnium, 92.

zygapophyses.— Articular processes in vertebræ, 177.

zygospore (Gr. *zygon* = a yoke + *spora*).— A spore formed by the union of two gametes, 94, 262.

zygote (Gr. *zygon* = a yoke).— A cell formed from the union of two others in sexual reproduction; a zygospore, 94, 262.

zymogenic.— Giving rise to fermentations.